NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

ANALYZING PERSONNEL RETENTION UTILIZING MULTI-AGENT SYSTEMS

by

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December 2000

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE December 2000	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE: Title (Mix case letters) Analyzing Personnel Retention Utilizing Multi-Agent Systems	**5. FUNDING NUMBERS**
6. AUTHOR(S)) French, Stevan J.	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	**12b. DISTRIBUTION CODE**

As we enter the 21st Century, the Department of Defense finds itself facing a significant personnel crisis. Despite a thirty percent reduction in manpower needs, the military is continually failing to meet its retention requirements.

There are numerous factors that are causing this problem, to include the booming US economy, the highest military deployment rates in our history, and the widespread use of the Internet. The result is that our service members have more non-military career options than ever before, and too many are choosing them. The problem appears to be getting worse as recent surveys indicate that over 50 percent of the enlisted force, and over 33 percent of the officer force intend to leave the military at their next opportunity.

The drastic change in retention behaviors did not occur overnight, yet the military failed to react quickly to the change. The reason for this is that strength projections are calculated using linear models, which are based upon historical data; these programs are incapable of warning about non-linear behaviors. If the military had used supplemental non-linear models, we most likely would have been able to react sooner.

This Thesis therefore provides the Military Personnel Retention Simulator (MPRS), a model for exploring non-linear retention behaviors in an ever-changing environment. The model utilizes modern object-oriented programming, high-speed processors, and multi-agent system concepts in order to provide an un-situated environment which users can manipulate in order to observe potential retention behaviors. The model is exploratory in nature, and is therefore not predictive. Users are therefore urged to utilize the MPRS in support of the decisions that they make, and not as the basis for such decisions.

14. SUBJECT TERMS Modeling, Simulation, Retention, Multi-Agent Systems, Complex Adaptive Systems, Strength Management, Manpower Forecasting	**15. NUMBER OF PAGES** 156
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

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ANALYZING PERSONNEL RETENTION UTILIZING MULTI-AGENT SYSTEMS

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MODELING, VIRTUAL ENVIRONMENTS, AND SIMULATION

from the

NAVAL POSTGRADUATE SCHOOL
December 2000

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ABSTRACT

As we enter the 21st Century, the Department of Defense finds itself facing a significant personnel crisis. Despite a thirty percent reduction in manpower needs, the military is continually failing to meet its retention requirements.

There are numerous factors that are causing this problem, to include the booming US economy, the highest military deployment rates in our history, and the widespread use of the Internet. The result is that our service members have more non-military career options than ever before, and too many are choosing them. The problem appears to be getting worse as recent surveys indicate that over 50 percent of the enlisted force, and over 33 percent of the officer force intend to leave the military at their next opportunity.

The drastic change in retention behaviors did not occur overnight, yet the military failed to react quickly to the change. The reason for this is that strength projections are calculated using linear models, which are based upon historical data; these programs are incapable of warning about non-linear behaviors. If the military had used supplemental non-linear models, we most likely would have been able to react sooner.

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LIST OF SYMBOLS, ACRONYMS AND ABBREVIATIONS

- AAR: After Actions Review
- ACAP: Army Career and Alumni Program
- ACCP: Aviation Career Continuation Pay
- ACOM: Above Center of Mass
- ACP: Aviation Continuation Pay
- ADELE: Agent for Distance Learning
- AEA: American Economic Association
- AFIT: Air Force Institute of Technology
- AI: Artificial Intelligence, Artificially Intelligent
- BCOM: Below Center of Mass
- BUPERS : US Navy Bureau of Personnel Affairs
- CA: Cognitive Agent
- CARTE: Center for Advanced Research in Technology and Education
- CAS: Complex Adaptive System(s)
- CG: Computer Game(s)
- CGF: Computer Generated Forces
- CHAMUPS: Civilian Health and Medical Program for the Uniformed Services
- CNN: The Cable New Network
- COM: Center of Mass
- CR: US Navy continuation rates
- CSC: US Army Command and Staff College
- DMDC: Defense Management Data Center
- DoD: Department of Defense
- DTIC: Defense Technical Information Center
- EAD: Entered onto Active Duty
- ECC: Embodied Conversational Character(s)
- ER: Early Retirement
- ETS: Expiration, Time of Service (end of enlistment contract)
- FPS: First Person Shooter
- GA: Genetic Algorithms
- GUI: Graphical User Interface
- HCI: Human-Computer Interaction
- HHCA: Human-Human Conversation Analysis
- IRAD: Involuntary Reduction in Active Duty
- ISAAC: Irreducible, Semi-Autonomous Adaptive Combat
- LAN: Local Area Network
- LPF: Least Penalty Function
- MAS: Multi-Agent System
- MIT: Massachusetts Institute of Technology
- MORS: Military Operations Research Society

- MOS: Military Occupation Specialty.
- MOVES: Modeling, Virtual Environments, and Simulation
- MPR: Military Personnel Retention
- MPRS: Military Personnel Retention Simulator
- MRC: Major Regional Crisis (es)
- MSR: Minimum Service Requirement
- NATO: North Atlantic Treaty Organization
- NCO: Non-Commissioned Officer
- NFO: Non-Flying (Aviation) Officer
- NMC: Non-Mission Capable(The unit is incapable of performing its
- wartime mission).
- NPS: Naval Postgraduate School
- OCS: Officer Candidate School
- ODCSPER: Office of the Deputy Chief of Staff
- OMF: Officer Master File
- OOP: Object-Oriented Programming
- OOTW: Operations Other Than War
- OPSTEMPO: Operations Tempo
- PA: Pedagogical (teaching) Agents
- PaYS: Partnership for Youth Success
- PERSCOM: US Army Personnel Command
- PICAS: Pilot Inventory Complex Adaptive System
- PR: Personnel Retention
- RA: Reactive Agent
- RCP: Retention Control Points
- REA: Real Estate Agent (simulator)
- RIF: Reduction in Force
- ROTC: Reserve Officer Training Corps
- R&R: Recruiting and Retention
- SDG Swarm Development Group (at the SFI)
- SFI: Santa Fe Institute, New Mexico
- SM: Strength Management
- SOAR: Simulation and Operation of Autonomous Robots
- STEVE: SOAR Training Expert for Virtual Environments
- SSB: Special Separation Benefit
- SSS: Swarm Simulation System
- SWO: Surface Warfare Officer
- USAREUR: The United States Army, Europe
- USMA: (US Army) United States Military Academy
- VE: Virtual Environment(s)
- VSI: Voluntary Separation Incentive
- YATS: Youth Attitude Tracking Survey
- YOS: Years of Service

EXECUTIVE SUMMARY

As we enter the 21st Century, the Department of Defense (DoD) finds itself facing a significant personnel management crisis. Despite a thirty percent reduction in manpower needs over the last ten years, the military is continually failing to meet its recruiting and retention requirements. This failure has created a vice-like effect upon the DoD's capability to properly man and train many of its units, thus contributing towards a lower overall readiness state for our Armed Forces.

This reduced readiness was most recently observed when the United States participated in NATO's intervention in Kosovo. During this Operation Other Than War (OOTW), US Air Force and Navy combat pilots were not as effective as was expected. Furthermore, US Army aviation units failed to meet training standards for their utilization. The stress of multiple deployments showed during this period. The best representation of this fact was that two Army Divisions were labeled "non-mission capable" (NMC). The Congress is now investigating whether or not the military is capable of meeting its requirements (to fight and win two simultaneous Major Regional Crisis' (MRCs).

The readiness problem might not be so stark if OOTWs were few and far between. Unfortunately, the frequency of such missions has continued to increase since the Gulf War (the United States Army, Europe (USAREUR) alone has seen a 500% increase in OOTW [Ref 23]). In November 1999, Cable New Network (CNN) reported that almost two-thirds of voters support the continued use of the military for missions such as Kosovo [Ref 25]. This means that our civilian leadership will most likely continue to utilize the Armed Forces for OOTW missions.

However, deployments have their personnel cost. They increase the amount of time that service members are away from their families. When the OOTW includes the possibility of combat, family stressors increase dramatically. The result is an additional negative factor influencing retention. When this is combined with other factors such as the booming civilian economy, the perceived decrease in retirement benefits (especially medical), and quality-of-life issues, the combinatory effect is dramatic.

The problem is amplified by the impact of the information revolution; the widespread use of the Internet by our service members keeps them very well informed about their non-military employment opportunities. The result is that the number of service members leaving the service continues to rise.

In October 1999, *The Military Times* reported that more than half of the enlisted force intended on departing the military as soon as possible (the Navy was highest with 75%). The commissioned officer side of the survey showed that at least 33 percent of all officers intended to leave (the Army was highest with 53%) [Ref 13]. Many of those who plan to get out are those with critical skills such as computer specialists, technicians, and aircraft pilots. As of July 2000, 23 of the Army top 25 most critical MOS were computer operators or technicians. These Military Occupation Specialties (MOS) are found in Table 2.5 [Ref 24].

A significant portion of the current crisis stems from DoD personnel management decisions made during the post-Cold War "drawdown" of the 1990s. The drawdown reduced the active force from 2 million down to 1.4 million service members. When the plans for the drawdown were being created, the American economy was believed to be in a state of recession. Under that belief, it was thought that a mass involuntary separation

would simply pour 600,000 of the least qualified service members into the unemployment lines, thus making the economy even more depressed. Therefore, Congress authorized monetary incentives for early retirements and voluntary discharges. The incentives included lucrative deals such as the Voluntary Separation Incentive (VSI) and the Special Separation Benefit (SSB).

The target of the incentives was still the lower-qualified service members, but these plans would allow them to re-enter the work force gradually (as they had money in their pockets), and would allow many of them to start up their own businesses; things that should improve, and not hurt the economy. Unfortunately, the economy was no longer in a state of recession, and the result was disastrous. Many of our best-qualified personnel reviewed their situations, and found it to their personal advantage to depart the service; these personnel not only departed directly into high-paying civilian jobs, they were paid by the government to do so.

The perception of military employment also changed during this time; many civilians gained the perception that the military was not recruiting anymore, and those that left the military for civilian employment were spreading the perception that military careers were no longer viable. The military actually had to advertise that we were still hiring!

As the services were only using linear programs to study retention behaviors, and as we were trying to eliminate over half of a million positions, the dramatic change in retention behaviors was not detected until it was too late. During the last half of the 1990's, the military has found itself trying to regain this lost ground. To date, the Army is actively trying to convince VSI and SSB soldiers to come back [Ref 26].

Had military manpower experts properly understood the retention factors they were facing in the early 1990's, it is easy to see that they would have made many decisions differently. But how could they have known, and how do current and future decision-makers stop from making the same kinds of mistakes? Furthermore, how can they know which factors they should manipulate (of those they can)?

Although we can blame technology for amplifying this problem, we can also look to technology to help solve it. This thesis takes advantage of today's dramatically increased processor speeds, modern object-oriented programming, and non-linear Agent-based techniques in order to provide a non-linear supplement to the current linear model only approach.

The model is called the Military Personnel Retention Simulator (MPRS). The MRS is designed to help personnel managers fully understand all possible ramifications of their decisions. While it cannot predict the future, it can show the scope of possible futures through the use of exploratory modeling. When used as a supplemental analysis tool, this model will be able to warn personnel strength managers of problems they may encounter.

The model utilizes computerized objects ("Agents") to create a Multi-Agent System (MAS). The Agents emulate the behaviors of a specific critical military community. The MAS changes the environment that the Agents "live" in. Thus, personnel managers can observe what large-scale "group" retention behaviors may result after they implement a particular policy.

The model comes with a Graphical User Interface (GUI) to help guide the user through the process. The GUI provides a demonstration of how the MPRS works. It also

solicits input into how the user would like to run his/her own simulations. This eliminates the necessity of each user having to be an expert in the Java Programming Language in order to alter what specialty is studied, and the strengths of each factor used in the study.

The model is exploratory in nature, and therefore not predictive. The user is urged to use this model in support of the decisions he/she makes; it should not be used as the basis for such decisions.

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ACKNOWLEDGMENTS

I would like to express my sincere thanks to my professors in the MOVES, Operations Research, and Computer Science departments who have dedicated themselves towards the betterment of Department of Defense through their efforts in educating DoD officers and civilian employees. In particular, I would like to thank Professors Michael Zyda, John Hiles, Michael Capps, John Falby, William Krebs, Barry Peterson, and Samuel Buttrey; although only three of these names appear on my thesis, all of them played a significant role in this work. In addition, I would like to thank my classmates, all of whom had an impact upon my education.

I would also like to thank my wife Debora, and my children Nicole, Matthew, and Hunter, all of whom serve as my inspiration, and make my life the joy that it is to live.

Most importantly, I thank God for giving us this Country to live in, and this life to share with each other.

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I. INTRODUCTION

> "Whereas the purpose of induction is to find patterns in data and that of deduction is to find consequences of assumptions, the purpose of agent-based modeling is to aid intuition." --- *Robert Axelrod*

A. THESIS STATEMENT

A multi-agent system simulation in support of personnel retention analysis provides personnel managers with a thinking tool to help them better understand and forecast the retention behaviors of service members.

B. THESIS MOTIVATION

The Naval Postgraduate School has long had a reputation for quality research in both the areas of military retention, and of artificial intelligence. Over the last ten years, significant changes have occurred in both fields. One of the driving forces behind the changes in both areas is the Technological Revolution. Like the Industrial Revolution, the most significant changes involve how quickly things get done.

1. Retention

In the area of military retention, service members can now gain access to unlimited amounts of information about the civilian job market, and they are finding that there are numerous opportunities for them, regardless of their military occupation specialty (MOS). Those service members with technical backgrounds have even greater opportunities. The result has been that service members are departing the service in much larger numbers, both before and after they are retirement eligible.

Many service members are opting to leave the military before retirement because they see their financial opportunities as being greater getting out immediately, rather than

after earning a retirement check. Other service members are retiring, but they are not staying in the service until they reach their retention control point (RCPs), which exceed the 20-year benchmark by up to ten years. These changes have caused significant challenges to the linear retention models that the services use; even the Air Force (long known for its high retention rates) has been caught off guard by technical and mechanic MOS personnel departing in extreme numbers. These drastic changes have presented a new challenge to NPS operations analysts.

2. Artificial Intelligence

In the area of Artificial Intelligence (AI), processor speeds have increased so dramatically, that many applications previously deemed conceivable, but not practical, have come to fruition. One such concept is that of using a computerized object to represent each part of a large system. The objects (called "agents") are now being used to develop new computer software programs around the world. Agents are appearing everywhere from inside electronic equipment and videogames, to modeling the behaviors of insect colonies, to surfing the Internet on behalf of a user so that the user does not have to waste personal time doing routine tasks.

Agent technologies are skyrocketing, and adding new breath into the AI community. In 1998, the NPS hired an agent software developer (Professor John Hiles) to support agent-based projects and to teach agent-programming techniques. These courses have spurred numerous theses to develop, analyzing everything from communications to armed helicopter reconnaissance. In addition, major agent-based simulation projects are now under way, making the NPS a significant player in agent-based research and development.

3. Using Agents for Operations Analysis

Midway through the 1990's, an NPS computer scientist named Professor Michael Zyda saw the need for merging Operations Analysis with Computer Science. He therefore created a new Academic Group at the NPS entitled "Modeling, Virtual Environments, and Simulation" (MOVES).

The MOVES Academic Group utilizes the academic assets of both the Operations Research and Computer Science Departments. This interdisciplinary approach benefits both students and professors. The professors benefit by working with each other, and learning how to incorporate the "sister" field into their own. One such professor was Doctor William Krebs who conceptualized the merging of agents into his field of military retention analysis. Professors Krebs and Hiles therefore agreed to co-advise the development of this military retention simulator. Six months prior to the release of this thesis, Professor Krebs transferred to the Federal Aviation Administration, and was replaced by Professor Zyda as thesis advisor.

C. THESIS SCOPE

This model is being provided as a thinking tool to use as a supplement to current linear models. It is exploratory in nature, and therefore not predictive. The user is urged to use this model in support of the decisions that he/she makes, and not as the basis for such decisions. If the model predicts behaviors contrary to the user's expectations, the user should take this as a warning sign that environmental conditions may be primed for extreme, if not chaotic behavior changes.

This model is designed to emulate the retention behavior of unique communities within the DoD. As such, the user must be intimate with the knowledge about the

community that he/she is attempting to model; the level of the quality of the information input into the model will drive the quality of the output derived from the model. This model also calls for the user to interpret the perceptions that the community has about pay gaps, and the extent to which the chains of command and the DoD care about the individuals in the community; if survey information for a specific community can not be obtained (from the Defense Management Data Center (DMDC) or other resources), the user should make estimates based upon the feedback that he/she receives when dealing with members of that given community.

Although the model is designed to emulate homogeneous sub-communities within the DoD, it could conceivably be expanded for larger, more general groups of service members. However, the user should note that as the behavioral input goes from specific to general, the associated output will become less accurate, and of less use.

The model is designed to produce outputs that are displayed for the user on the DOS Command Line. Analysis of this output is beyond the scope of this thesis and is designated as future work.

D. THESIS OBJECTIVE

The purpose of this study is to provide military personnel managers an advanced computer simulation model that will assist in the study of non-linear retention behaviors of critical military professions. My intent is that the MPRS model be used to supplement the current top-down structured models in all branches of the Armed Forces for the analysis of any critical skill.

The primary target for analysis is critical commissioned officer specialties from within any branch of the Armed Forces. The secondary targets for analysis includes critical enlisted and warrant officer specialties. Tertiary targets include larger, non-homogenous groups of servicemen from the same career path (commissioned officer/warrant officer/enlisted).

Properly utilized, the MPRS will provide the full spectrum of possible changes in trends, thus making the user cognizant of potential problems. This model is designed to provide personnel retention decision-makers with a thinking tool that will supplement traditional models; it is not meant to be their replacement.

E. THESIS ORGANIZATION

This thesis is organized into the following chapters:

- Chapter I: Introduction. Identifies the purpose and motivation for creating this model. Establishes the objectives for this thesis. Explains the organization of this thesis.
- Chapter II: Background. Discusses the background of the current military manpower crisis. Discusses the advances in computing power that has allowed agent-based simulations to advance.
- Chapter III: Previous Research and Literature. Discusses the research conducted in the fields of Military Retention and Complex Adaptive Systems. Discusses recently released and relevant papers. Defines key concepts and terms.

- Chapter IV: Model Development: Describes the development and purpose of the model. Identifies file hierarchies and defines each of the twelve major programming files. Explains how to obtain a copy of the model, and how to properly operate it. Discusses initial data analysis.
- Chapter V: Conclusions and Future Work. Discusses information and concepts learned during the development of the model. Discusses future work to be completed by the author, and recommendations for other researchers.

II. BACKGROUND

"If we, as senior leaders, do not take action now to turn this around, we may not be able to meet our future requirements."
--- *General John M. Keane, US Army Vice Chief of Staff, 2000*

A. INTRODUCTION

General Keane's above-stated concern was about the 10.6 percent voluntary loss rate for captains (officer pay grade 3) that existed in the Spring of 2000. This rate has continued to grow, and is now nearly twice that of the pre-Operation Desert Storm Army [Ref 55]. This situation is just a symptom of a larger, DoD-wide problem.

B. THE RECRUITING AND RETENTION PROBLEM

Every year, the Defense Manpower Data Center (DMDC) produces a report called the "Youth Attitude Tracking Study" (YATS) for the Department of Defense. DMDC gathers the information for the study through interviews with young Americans, aged 16 to 24. The 1999 report shows the continuation of the trend away from military service throughout the 1990's. Although there are a number of reasons for this downward trend, the bottom line found in the report is that youths are no longer looking at the military as a primary source of preparing themselves for the future [Ref 37].

The YATS is just one of many DoD sources reporting negative information back on the personnel challenges facing the Armed Forces here at the beginning of the 21st Century. The military personnel system has thus entered an uncharted era of constant change in both the recruiting and retention (R&R) arenas that is threatening our military readiness posture.

The constant change in R&R behaviors has caused a personnel crisis unlike any that the DoD has ever had to deal with since the implementation of the "all volunteer" force. Despite reducing the total number of personnel needed by the active forces by over thirty percent, the DoD still finds itself unable to consistently retain the right amount and types of personnel that it needs. This problem is further complicated by the DoD's inability to recruit enough new service members to replace its losses [Ref 28]. These simultaneous problems act like a vice upon the personnel strength management of each service.

1. Enlisted Recruiting

The enlisted force is traditionally the focus of recruiting. Unfortunately, YATS numbers indicate that the prime target for recruitment (16-to-21-year-olds) has lost almost 30 percent of their interest in joining the military since 1989 (going from 17 percent to 12 percent during the decade). Tables 2.1, 2.2, 2.3, and 2.4 reflect the enlisted military recruiting results over the last five years, as reported by CNN in October 2000 [Ref 25].

U.S. Military Recruitment, 1995-1999		
U.S. Army		
Fiscal year	Goal	Achieved
1995	63,000	62,967
1996	73,400	73,528
1997	82,000	82,087
1998	72,550	71,749
1999	74,500	68,210
Source: S. Douglas Smith, Public Affairs Officer, U.S. Army Recruiting Command		

Table 2.1: US Army Recruiting, 1995-1999 (from Ref 25)

U.S. Military Recruitment, 1995-1999		
U.S. Navy		
Fiscal year	Goal	Achieved
1995	48,637	48,637
1996	48,206	48,206
1997	50,135	50,135
1998	55,321	48,429
1999	52,524	52,595

The Navy's goals are predictions for Congress of how many sailors will leave during a given year. Actual recruitment is eventually adjusted to match actual attrition.
Source: Lt. Steve Zip, Deputy Public Affairs Officer, Navy Recruiting Command

Table 2.2: US Navy Recruiting, 1995-1999 (from Ref 25)

U.S. Military Recruitment, 1995-1999		
U.S. Marine Corps		
Fiscal year	Goal	Achieved
1995	38,625	38,643
1996	39,465	39,484
1997	40,369	40,716
1998	40,325	40,366
1999	39,414	39,503

Source: Sgt. Katesha Niman, Public Affairs, Marines Corps Recruiting Command

Table 2.3: US Marine Corps Recruiting, 1995-1999 (from Ref 25)

U.S. Military Recruitment, 1995-1999		
U.S. Air Force		
Fiscal year	Goal	Achieved
1995	31,000	31,000
1996	30,700	30,700
1997	30,200	30,200
1998	31,300	31,491
1999	33,800	32,068
The Air Staff at the Pentagon annually sets goals for recruitment based on attrition, then when those goals are met the figures for actual recruitment are adjusted to match them. Therefore, in years that are closed on the books, figures for goals and actual recruitment are the same. Source: Master Sgt. Thomas Clements, Superintendent, Air Force Recruiting Service Public Affairs, U.S. Air Force		

Table 2.4: US Air Force Recruiting, 1995-1999 (from Ref 25)

The above tables reflect that the three main services (Army, Navy, and Air Force) have all had a significant enlisted recruiting problem during the last two years. The Army's most severe problem was an eight percent failure in 1999; the Navy's was a twelve percent failure in 1998, and the Air Force's was a five percent failure in 1999. The Air Force's failure was significant, in that it is normally perceived as the service of choice amongst eligible recruits.

The Marine Corps did not have a recruiting problem during the five-year period analyzed; this is mostly due to its MOS configuration brought about with its association with the Navy. The current enlisted R&R problem appears to be one primarily involving special skilled personnel such as computer specialists, mechanics, and technicians. As the Marine Corps primarily consists of combat arms MOS, it is able to focus its recruiting advertisements on its image as an elite combat force. Table 2.5 (Army Top 25 Critical MOS for May 2000) reinforces this concept, reflecting only two combat arms MOS (note that Air Defense Artillery crewmembers are considered to be technicians).

MOS	Title	Rec. Priority	FY 00 Proj. Op. Str
13F1	Fire Spt Specialist	1	94%
13M1	MLRS Crewmwmber	1	90%
14E1	Patriot FC Op/Maintainer	1	91%
14T1	Patriot LS Op/Maintainer	1	94%
14S1	Avenger Crewmember	2	97%
19D1	Cavalry Scout	1	99%
27E1	LC Elec Msl Sys Rep	2	92%
31F1	Network Sw Sys Op	2	91%
31R1	Mech Xmission Sys Op	1	94%
35E1	Radio/Comsec Repairer	2	88%
52D1	Power Gen Eq Repairer	2	94%
54B1	Chemical Operations Spec	2	95%
63B1	LT Wheel Vehicle Mec	2	91%
63D1	SP FA Sys Repairer	2	92%
63S1	Heavy Wheel Veh Mech	1	88%
67S1	OH-58D Helicopter Rep	2	97%
67T1	UH-60 Helicopter Rep	2	100%
77F1	Petroleum Supply Spec	2	89%
92R1	Parachute Rigger	2	93%
92Y1	Unit Supply Specialist	2	91%
93C1	Air Traffic Control	2	82%
96B1	Intelligence Analyst	2	99%
98C1	EW/Sigint Analyst	1	83%
98J1	Non-Commo Interceptor	1	85%
98X1	EW/Sigint Recruit	1	94% (98G)

Table 2.5: US Army top 25 critical MOS for July 2000 (from Ref 24)

2. Enlisted Retention

Perhaps the only challenge to the military as significant as its enlisted recruiting problem is its enlisted retention problem. Concern for retention can be seen in the communications of the leaders at every level of command, and within each service.

Concern for enlisted retention appears to be growing strongest within the Air Force. In the past, retention was a word that the Air Force normally only used when discussing their efforts to keep their pilots. In October 1998, *Air Force Magazine* detailed the problems that the Air Force was beginning to have with its enlisted retention [Ref 34]. In this article, Air Force Chief of Staff (General) Michael E. Ryan stated that

the problem needed to be addressed seriously, even discussing the concept of reducing OPSTEMPO in order to aid enlisted retention.

Despite the Air Force goal of retaining 75 percent of its first term airmen, it is seeing extremely disheartening numbers in their technical-skill MOS, to include air traffic controllers at 52 percent and communications-computer system controllers at an incredulous 31 percent (see Table 2.6 for more Air Force critical MOS information). It is obvious that the close association between these Airmen and their civilian counterparts plays a large role in the poor retention rates. The problem appears to be getting worse for the Air Force as reflecting in the July 2000 issue of *The Times,* which reported that the Air Force was missing its retention goals in all categories [Ref 35].

Top 10 Watch List, Enlisted Retention			
Year	**1st Term**	**2d Term**	**3d Term**
Combat Controllers	43%	100%	95%
F-16 crew chiefs	68%	66%	92%
Airborne BM pers	40%	64%	100%
Com-Computer ops	57%	61%	88%
Pararescue jumpers	56%	55%	85%
Air traffic controllers	41%	52%	89%
Space systems ops	52%	51%	88%
Security forces	38%	66%	93%
Crypto-linguists	41%	53%	94%
Com-computer sys con	42%	31%	85%
Source: USAF, Fiscal 1998 figures are for the first three quarters			

Table 2.6: Air Force Top 10 Critical Enlisted MOS (from Ref 35)

To find the root of the Air Force problem, they polled their service members on four subsets of what they called "General Well Being." Table 2.7 is the results of that poll. Of note, pilots (despite being officers) had the lowest ratings for their perceptions of how well they were kept informed by the Air Force (even lower than junior enlisted

airmen); they also ranked last in how well they stated their families supported their careers (this may be a factor of pilots being the significant combat fighters in the Air Force).

The junior enlisted retention problem is highlighted in these numbers by being second behind the pilots in both aforementioned categories, and first in the other two categories ("Is the Air Force a good place to work?", and "Does the Air Force provide a good quality of life?") [Ref 49]. Unfortunately, the Air Force was unable to react quickly enough to these warning signs, and in 1999 suffered a significant manpower setback.

Air Force General Well Being							
	% Officer			**% Enlisted**		**% Civilian**	
	Jr.	Field	Pilot	1st Term	2nd Term	Jr.	Sr.
USAF is a good place to work	81	83	71	69	68	83	81
USAF provides good quality of life	76	77	67	66	60	76	75
Family supportive of career	71	78	59	63	60	82	83
How well USAF informs	47	54	40	45	41	51	49

Table 2.7: Air Force Poll on Attitudes towards service, August 1998 (from Ref 34)

Similar problems are being found in all other branches of service. The Army is attempting to counter this problem by increasing their annual enlisted bonus program budget by 64% (from 50 million to 82 million dollars per year). In some cases, the Army is seeing that no amount of additional bonus money will retain soldiers with hot MOS. In an attempt to embrace the problem, the Army has started a new program called PaYS (Partnership for Youth Success) which provides young Americans hiring preference with numerous civilian corporations after serving a tour with the Army [Ref 38]. Although the

PaYs program does not fix the retention problem, it increases the number of soldiers entering the Army, thus providing some relief.

Another negative retention trend is being seen within the non-commissioned officer ranks (senior enlisted). Retiring service members throughout the Armed Forces are departing at 20-years at a significantly higher rate. In the past, the military could always count on many of these NCO's to stay in until they had to leave under the RCP Program (which allows service members to remain in the military for up to ten additional years, based upon their rank). The current trend appears to indicate that retirement-eligible NCO's are rushing to civilian employment, much the same as those junior enlisted service members who are choosing to ETS.

3. Officer Retention

While R&R programs have traditionally been seen as enlisted personnel management problems, they are now also becoming problems for officer personnel management. Mid-career officers are exiting the military at an alarming rate. In October 1999, *The Military Times* reported that over one-third of the officers in every service intended on departing the military as soon as possible [Ref 13]. This trend has been growing since the end of the cold war. In 1989, only 6.7 percent of Army captains left the service voluntarily each year; this rate has increased almost 60% since that time, sitting at 10.6 percent for 1999 [Ref 30].

While it might be thought that the officer personnel resigning are not the quality officers that the military wants to keep, it should be noted that this dissatisfaction has now appeared at the US Army's Command and General Staff Course (CGSC/CSC). When Army Chief of Staff General Eric K. Shinseki commissioned a survey of students

at CSC, the results were astounding. Although the results of the meetings were supposed to be for internal-Army use only, they quickly leaked out, and were spread across the Internet via electronic mail. The results showed that even these officers, being primed to be tomorrow's senior-Army leaders, were greatly dissatisfied, and many intended on leaving before they become retirement eligible [Ref30].

The Navy is also experiencing a significant loss in commissioned officers. A 1999 Navy survey found that many officers did not want to be put into leadership positions because they did not want to be micromanaged. Although the Navy offers a 50,000-dollar bonus for taking such "Department Head" tours, they were having problems getting officers to take them. Another significant reason for avoiding these jobs was the workload. While all other branches can count on reserve units to take rotations, there are no ships in the Navy Reserves. Navy reservist can only supplement working crews on an individual basis, which does not alleviate the additional workload and stressors emplaced upon Department Heads [Ref 36].

Air Force pilot retention is thoroughly discussed by Captain Marty Gaupp, in his thesis completed at the Air Force Institute of Technology (AFIT) [Ref 2]. This specialty is going through phases that prove Captain Gaupp's assumption that a Complex Adaptive System (CAS) was appropriate for modeling pilot retention. In October 1998, *Air Force Magazine* also reported extreme changes in retention behaviors that caused the Air Force to lower their projected pilot strength by over 30 percent within a few months of their original projection! [Ref 34].

4. Officer Recruiting

The officer-recruiting problem also appears to be getting worse. In July 2000, the *USA Today* reported that for the fifth straight year, both the Army and Navy failed to attract enough qualified persons to serve as newly commissioned officers; the report also stated that the Air Force was also having sporadic problems with recruiting new officers. While the Army has been able to overcome their problem with a short-term solution of expanding its Officer Candidate School (OCS, a school which trains enlisted soldiers to become Army officers) Program, the Navy's OCS Program will not be able to make up their shortage.

It should be noted that the Army's short-term solution to fix their officer recruiting problem actually worsens its enlisted retention problem, as it strips the enlisted ranks of an additional layer of highly-qualified non-commissioned officers (NCO's). Furthermore, it strips the Army of some of its best future leaders; while these NCO's should make outstanding junior officers, most will never become senior officers, as they will end up meeting the Army's RCPs, and being forced to retire before they reach senior officer ranks. We cannot underestimate the value of having highly qualified NCO's advising tomorrows senior-level Army officers.

The long-term solution for fixing the enlisted recruiting problem is to expend more resources on the problem. The military is therefore increasing its spending on advertising, the number of recruiting stations, and the incentives that it is giving out to join the military. The military is also dedicating an increased number of service members to serve as recruiters.

The long-term solution for officers provides an extra level of difficulty. During the drawdown, the military closed a significant number of Reserve Officer Training Corps (ROTC) detachments and sub-detachments. Reopening these detachments is significantly more difficult than renting local mall space (where we are trying to emplace many of our enlisted recruiting stations). Reopening an ROTC detachment means going through the politics of each college campus, many of which do not want an ROTC presence. Adjusting the ROTC-recruiting base is not an easy task, and will always lag behind the current needs of the military.

5. The Changing Civilian Environment

The retention and recruiting situations are actually just symptoms of a larger overall problem: The current employment environment in the United States makes civilian employment much more attractive than military employment. This environment consists of many factors such as pay, duty hours, benefits, and quality of life.

In the past, the military was very appealing to high school graduates who could not obtain a college scholarship. The military was seen as a place where young adults could learn skills, earn college money, and pursue adventure. Many college students became officers for similar reasons; the military was a good job that provided young officers skills and adventure. Many of these service members stayed in the military until retirement because the lifestyle was deemed acceptable (and often times more attractive than the civilian-sector alternative).

In the late 1980's, military employment had an added advantage due to the US economy's entering a recession. After the conclusion of the Gulf War in 1991, all eyes were focused on the economy. Both the Executive and Legislative Branches of the

Federal Government believed that a reduction in force (RIF) was appropriate, and that the "peacetime dividend" resulting from the RIF might help the government out of the recession. The government therefore created plans for the "drawdown."

6. The Drawdown

Rather than reducing the forces via massive involuntary separation boards, Congress deemed it more appropriate to provide incentives to encourage personnel to leave the military for civilian employment. Examples of these programs include the Voluntary Separation Incentive (VSI), the Special Separation Benefit (SSB), and Early Retirement (ER). The hope was that the resulting Armed Forces would consist of highly qualified personnel who truly wanted to serve in the military; it was also hoped that those lower qualified personnel would take the incentives. What the Congress and military did not perceive was that the civilian employment environment had already bottomed out, and was in a state of recovery. The civilian sector would end up absorbing all that the military wanted to release, and more.

As the civilian economy "roared back to life," more and more service members began perceiving the civilian environment as being more attractive than the military environment. Both word-of-mouth, and information provided via the Internet convinced many of the military's best service members to depart the service. The economy continued to grow throughout the 90's, spurring more and more service members to resign or ETS (leave the service at the expiration of their time in service requirement). Currently the services are trying to get some of these lost service members back into the service [Ref 26].

7. The Technological Revolution

One of the most significant reasons for the US economic turnaround has been the technological revolution. Events such as the Congress opening up the Internet, and the exponential increase in computer technologies have spurred the creation of numerous new companies, and the expansion of many older ones. This expansion has driven down the civilian unemployment rate to a range that Keynesian Economist previously believed to be unobtainable (below 6.5 percent unemployment). Transitory unemployment is now almost unheard of, as individuals already have new jobs lined up before they leave their old ones (the phenomena is most prevalent in the technologies sector).

The civilian economy has gotten to the point that there simply are not enough employees in many sectors. Technological companies alone need well over 250,000 more employees, and they see the military as an employment pool to fill many of those jobs. Furthermore, these companies directly compete with junior colleges and the military for high school graduates. The end result has been that graduating high school students now have more options available to them than any group of their predecessors.

8. The Changing Military Environment

During the decade of the 1990's, the military environment has also been changing; unfortunately, the general perception is that the change has been for the worse. Both current and perspective service members are being heavily affected by the perception that the military provides an inferior lifestyle than the civilian sector. There have been many reasons for this:

- The number of service members receiving government and civilian relief has highlighted the difference in military-to-civilian pay. While FY2000

will see a significant pay jump for officers, and FY2001 will see a significant pay jump for enlisted, the perception has already been created that the military is not a good environment for young families, and that the military is not taking care of its own [Ref 27]. When FY2000 basic pay for private (E-1's) is divided down into an hourly rate, it equates to $5.37 [Ref 28], far below what fast food restaurants are offering in most major cities.

- The restructuring of active and retired medical benefits in order to save money continues to take its toll. Many service members now think that their (and their dependents') medical benefits are lacking. Worse yet, these service members are observing their predecessors (military retirees), appealing to the government for help in protecting their benefits, and launching lawsuits in an attempt to preserve their medical benefits (e.g. HR 2966). This situation has even turned up in the political arena, where Senator John McCain used it during his unsuccessful bid for the presidency in 1999.
- The "Redux" retirement pay plan created a perception that military retirement pay was insufficient. Despite the reversal in this policy, the negative perception of inadequate retirement pay still exists. It also leaves the question in many minds as to whether or not the Redux Program will appear again should economic times become harsh again.
- The military caused the reduction of force structure to go slower than the reduction in personnel. This caused numerous units to be under-manned,

under-trained, and under-equipped. This created a new perception of the "hallow military" that the DoD stated it wanted to avoid. It also created a perception that the higher-ranking military leaders were preserving the force structure in order to maintain leadership authorizations for themselves.

- The increase in operations tempo (OPSTEMPO) within the military has greatly increased since 1991. After conclusion of the Cold War, and the US military's successfully defeating Iraq in the Gulf War, the United States has seen fit to use the reputation of its Armed Forces in order to exert political influence in numerous "hot spots" around the world. These Operations Other Than War (OOTW) have continued to keep the military in a high state of deployment. The number of OOTW missions for the United States Army, Europe (USAREUR) alone has increased by 500 percent since the conclusion of the gulf war. The timing of many of these deployments has also been a factor, as many have started just before the holiday season.

While it is impossible to exactly predict what the civilian employment environment will be like in the future, it is not necessarily the same case for the military employment environment. Many of the reasons that the military has become less attractive were, and are, controllable. Examples of controllable factors include the OPSTEMPO, the perceived civilian-military pay gap, and the perceived concern of local chain of commands, and the DoD.

The question that should be asked is "To what extent should we focus resources on each of these areas in order to exert control over them?" To date, the military is focusing its efforts on closing the pay gap with the civilian sector. However, historic manpower studies have shown that increased pay is not a good long-term input for increasing long-term job satisfaction. The Navy Department Head study supports this stand that money alone will not create job satisfaction [Ref 31]. The military must also focus on the work environment, and showing that they care for the troops (on both local commander and senior leadership levels).

Had previous military personnel planners been capable of studying all of the possible ramifications of their decisions before making them, they might have been able to make more accurate decisions. Furthermore, given a heads up, military planners could have reacted quicker to policies that were not having the desired affect (such as those dictating the drawdown).

Although the military has had computer models to help predict retention for quite some time now, these models are all top-down, linear programs. They study data over a long period of time and attempt to assign values to factors based upon this historic data. These models do a good job over the long run, but cannot react quickly to sudden, extreme changes in the environment. In the case of the drawdown, it took several years before we realized that too many people were getting out. The result was that we continued to pay people to leave, when at worst, we should have been reclassifying them to other MOS within our force structure.

The problem with using linear programs to predict human behavior, is that they are incapable of adequately representing the extreme group behaviors that can often occur. Linear Models assume that outputs will react in accordance with the inputs. However, when it comes to human behavior, one additional increment of input could have extreme outputs, and extreme amounts of input can have little, none, or a reverse effect.

In the area of military personnel retention, there is currently an additional problem when only using linear models. The military environment has changed so drastically over the last eight years, that historical data is almost irrelevant. Today's military environment is smaller, and is changing constantly as the military and Congress attempt to devise the right amount and types of units to have in the Armed Forces. These changes cause additional reactions in the behaviors of service members.

9. Affects of Human Interactions

In addition to the military system itself, there are other individuals associated with the system that can have a significant impact upon the retention behaviors of each service member. These individuals include military peers, mentors, civilian friends, and the family of each service member.

Military peers often have significant effects upon each other. These relationships can even have a greater impact than that of the chain of command. Often times, informal leaders are better able to sway the behaviors of organizations than those formally in charge of it. When this is a positive effect, the results can be outstanding, with units meeting goals that others only dream about; when it is a negative effect, the results often

cause leaders to be relieved (fired), and all involved to develop a bad perception about the organization as a whole.

Although the military does not have a formal mentorship program (beyond the rater-ratee system), almost every service member develops a relationship with a senior service member that continues past any formal boss-employee relationship. Sometimes this is a positive role model that the junior service member wants to emulate; other times, the senior service member is either a negative role model, or an example of what not to become. When junior service members observe what happens to senior leaders, they learn from it, and it has an effect upon their behavior.

Civilian friends also have an influence upon service members. Most importantly, they serve as liaisons between what life is like inside the military versus the civilian world. The impact can be considerable if the civilian friend performs the same type of work as the service member (for example, a civilian policeman who is the friend of a military/security policeman). These relationships allow direct comparisons between the pay, and lifestyles. If the civilian friend is an ex-service member, the impact can be even greater.

Perhaps the one group of people that have the greatest impact upon the retention behaviors of service members is his/her family. When people initially join the military, they normally have very few, if any dependents. As time passes, service members add additional dependents, and undergo life changes that have considerable impacts upon their retention behaviors:

- The Sailor who joined the Navy to see the world finds it progressively harder to deal with being absent from his young family for six months at a time.
- The Marine Officer who married after graduating from Annapolis, finds it harder to justify to his equally well-educated wife why they must move every one to two years, causing her to reset her career every each time such a move occurs.
- The Soldier with an exceptional family member (one with exceptional medical conditions) comes to realize that the medical care his child receives might be considerably better if he were working for a civilian company instead of relying upon CHAMPUS (Civilian Health and Medical Program for the Uniformed Services).
- The Air Force mechanic who cannot justify why she must receive civilian relief (food stamps, etc.) in order to take care of her four children, when her civilian friend is making twice as much working for United Airlines.

The bottom line is that as time passes by, the strain of the military lifestyle has a considerable impact upon a family. As statistics show that over 60 percent of the force is married [Ref 36], this impact affects the majority of our servicemen. All too often, this impact results in divorce; some reports indicate that the divorce rate for military marriages runs as much as 20 percent higher than the civilian divorce rate [Ref 32]. Regardless of whether or not a military marriage ends in divorce or not, the strain of the military lifestyle on families continually causes service members to re-evaluate their internal cost-benefit equation of continued military service.

C. ADVANCES IN COMPUTER TECHNOLOGY

While changes in the military have been negative, the changes within the computer industry have been extremely positive.

1. Modern Computing

This model utilizes recent technological and conceptual achievements that were unavailable when currently used linear-only models were developed. These advancements include the utilization of Java (the programming language of the present and the foreseeable future), and the modern concepts of object-oriented programming (OOP), and Multi-Agent Simulations (MAS). The model takes advantage of today's ever-increasing processor speeds in order to manipulate tens of thousands of objects in a parallel environment (a concept unheard of when current models were developed). Users should thus note that the model is best run with computers with processing speeds of 700 Megahertz or more.

2. The Complex Adaptive System Approach

The overall concept that drives this model is that of seeing the military personnel retention environment as being a Complex Adaptive Systems (CAS). CAS are systems that are comprised of many components or subsystems (up to millions) which when reviewed as a whole, display a group behavior. These behaviors change over time; sometimes they are rigid and unchanging, while others they may seem quite chaotic; normally, they fall somewhere in between these two extremes.

Dr. Brian Arthur of the SFI, and formally of Stanford University supports this definition with the paper he presented to the American Economic Association (AEA) during their 1994 annual meeting, entitled *Bounded Rationality*. In this paper he stated

that a CAS is a system that fluctuates between being rigid, and chaotic. The paper also states that inside a CAS, patterns do develop, but they involve constant change, and that the patterns are formed by the behaviors of the "actors" in the CAS who affect each other, and the system as a whole [Ref 41]. Professor Jacques Ferber supports these behaviors in his book *Multi Agent Systems* [Ref 42].

In the case of the military personnel retention system, the components are the service members within the military (or within a subset of the military), and the group behavior is the extent to which the service members decide to stay in the military or get out of it (including how much service members affect each other). At times in our past, retention was very predictable; over the last ten years, it has fluctuated, at times seeming most chaotic, specifically in regard to our technical MOS and pilots.

While the concept of CAS may seem foreign at first, we actually have a great deal of CAS around us in our daily lives. Some are natural, such as the cells in our body, and insect colonies; others are man-made (such as large-scale communications networks and artificial neural networks). Of these, insect colonies seem to be the easiest to understand, and perhaps the best example is that of an ant colony.

Each ant colony is comprised of thousands of ants which go about their daily lives with little knowledge about the colony as a whole. The ants perform their duties, interacting with each other, and influencing each other. Over time, the colony exerts numerous colony-level behaviors, none of which were directed by a "commander" ant; the behaviors are simply the result of the mass interactions of the member ants.

While there are numerous government agencies and private corporations studying CAS, the current research leader is the Santa Fe Institute (SFI), a private, non-profit,

multidisciplinary research and education center located in Santa Fe, New Mexico [Ref 39]. One of the most significant CAS projects at SFI is the Swarm Development Group (SDG), a group that uses its own Swarm Simulation System (SSS) to pursue state-of-the-art multi-agent based simulations [Ref 40].

3. The Appropriate Model for a CAS

As stated above, a CAS consists of up to millions of components or subsystems, which are called "actors." These actors all play similar, but different roles from one another. Worker bees have variations in how well, and how hard they do their work, and interact with each other; so do service members. In traditional models, we have to treat the individuals homogeneously; basically, we make them all the same. However, the aforementioned advances in technology and modern concepts allow us to create millions of unique individuals; the question now is how many different parameters to give the individuals!

The concept that allows us to model down to the actor level is agent-based simulations. A computerized object called an "agent" represents each actor. Each agent has a set of variables, and functions that set, get, and change the values contained in the variables. The parameters are set by random number generators owned by higher-level (environment-level) programs, which ensure that duplicate agents are the exception, and not the rule. The system as a whole is termed a Multi-Agent System (MAS), and will be discussed in further detail in later sections.

D. SUMMARY

Military personnel R&R behaviors are undergoing an unprecedented period of constant change. Modeling R&R behaviors thus becomes increasingly difficult as the behaviors depart from the constancy of the past to the almost chaotic behaviors they are exerting in today's military environment. Our failure to properly understand these changes has had a significant impact upon the readiness of the Armed Forces. Modern computer technologies now allow for the generation of more complex computer models to simulate the often chaotic-appearing behaviors of military personnel specialties. These behaviors can best be identified as being those of a CAS, and can now be modeled by advanced computer programs. Examples of simulation models replicating CAS can be found at a number of research facilities and private corporations, such as the SFI.

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III. PREVIOUS RESEARCH AND LITERATURE

> "Multi-agent systems bring a radically new solution to the very concept of modeling and simulation in environmental sciences, by offering the possibility of directly representing individuals, their behavior, and their interactions. Multi-agent simulation is based on the idea that it is possible to represent in computerized form the behavior of entities that are active in the world, and that it is thus possible to represent a phenomenon as the fruit of the interactions of an assembly of agents with their own operational autonomy." --- *Jacques Ferber*

This Thesis combines the studies of Military Personnel Retention, and modeling CAS with MAS. As the study of military retention has existed almost as long as the military, there are many sources for its study. The Naval Postgraduate School has led the way in this research, and has had numerous theses and papers published on the subject. This thesis will utilize several of the most recent and applicable NPS studies.

The remainder of the background research for this thesis concerns modeling CAS. Unlike military retention, the study of CAS is relatively new. The concepts were spawned at the SFI back in the mid-1980's, but the computer power necessary to properly execute the concepts was only available by using supercomputers. As the speed of personal computers began to skyrocket during the 1990's, CAS modelers began to find the capacity to experiment more with the concept of computerized agents. As processor speeds have continued to increase, so has the use, and therefore study of CAS. It is believed that this area will continue to expand and grow for the foreseeable future.

To date, only one paper has been found that combined the use of CAS and military retention (written at the Air Force Institute of Technology (AFIT) by Captain Marty Gaupp). Major Raymond Hill was Captain Gaupp's thesis advisor, and is the AFIT point of contact for CAS research [Ref 48].

A. RETENTION RESEARCH

Research on military retention is conducted throughout the Department of Defense. Materials for this thesis were located at the Naval Postgraduate School, the Air Force Institute of Technology, the Military Operations Research Society, and the Defense Management Data Center (DMDC). Additional information was provided by sources from within the Navy's Bureau of Personnel Affairs (BUPERS), and the Army's Personnel Command (PERSCOM).

1. Turner

In March 1995, Russell Turner published his NPS thesis *The Impact of the Military Drawdown on USN Aviator Retention Rates*. Turner's Thesis was on how the drawdown affected the retention decisions of Naval Aviators. It was a timely thesis, in that it was written long enough after the beginning of the drawdown to analysis the effects, but was also soon enough to provide timely feedback for decision makers. Turner was one of the first military researchers to state that the military should focus on group behaviors instead of individual behaviors.

Turner created a linear model in which he hoped the affects of the drawdown could be evaluated and then eliminated, thus leaving data that would have represented drawdown years that could be compared and contrasted with previous (and future) non-drawdown periods. Turner cut out involuntary separations so that he ended up with data

only on those officers who made their own decisions. He then conducted a regression analysis on his data to provide a quantitative estimate that could provide personnel decision-makers with a tool to adjust bonus monies based upon the desired retention rates of specific aviator communities.

Turner evaluated six factors in his study: the Aviation Continuation Pay (ACP), the Voluntary Separation Incentive (VSI), the Involuntary Reduction in Active Duty (IRAD), Minimum Service Requirement 2 (MSR2), MSR3, and civilian unemployment. One significant area Turner failed to analyze was the civilian pilot hiring rates.

Turner conducted a goodness-of-fit test on his factors and found that they provided a significant improvement in explaining the variation in Navy pilot continuation rates (CR). Turner's conclusion stated that a one percent increase in bonus money will have such affects as a 15.7 percent increase in the CR of jet pilots, or a 22.2 percent increase in the CR of jet non-flying officers.

Unfortunately, Turner's conclusions have not survived the test of time (which may have been drastically affected by the continued economic boom). Since the time of Turner's study, Navy pilot monetary incentive programs have continued to fail regardless of the additional monies they offered. To date, the Navy is still trying to find the right amounts of bonus money to provide to each aviation communities in order to raise pilot retention [Ref 44].

2. Bookheimer

William R. Bookheimer was also a student at the NPS. In March 1996, he published his thesis entitled *Predicting Naval Aviator Attrition Using Economic Data* [Ref 46].

Bookheimer's Thesis was on predicting Naval pilot attrition using economic data. While it provides good information on monetary issues, it sidesteps other critical issues such as quality of life. Bookheimer's focus was clearly on what economic conditions could signal a change in the retention behaviors of pilots. His study utilizes data from 1978 to 1990, which is now believed to be uncharacteristic of the current economy (with both the beginning and ending periods being in recessions).

Bookheimer separated his studied group into six sub-populations by dividing them into their distinct aviation communities (jet, helicopter, and propeller) and by how many years of service they had (5-8 or 9-12). He did not use any pilots who had four years of less service due to their not being eligible to voluntarily separate.

Bookheimer created three different linear regression models and found that no model was best at being able to predict retention rates for all six groups. He found that the national unemployment rate was the most useful factor that he studied, with the previous year's separation rate as the second most useful factor. He also found that the two groups that were most likely to separate were jet and propeller pilots with 5-8 years of service. These findings indicate that the Navy's biggest retention problem is at the pilot's first chance to separate.

3. Gjurich

Gregory D. Gjurich is a recent graduate of the NPS, having done so in March of 1999. His thesis was entitled *A Predictive Model of Surface Warfare Officer Retention: Factors Affecting Turnover* [Ref 47].

Gjurich studied the factors that affect personnel turnover. Although his focus was on Naval Surface Warfare Officers (SWOs), his study shows many factors that affect all

specialties, particularly commissioned officers. Gjurich utilized logistic regression, and classification trees to determine how strongly these factors affect retention behavior. It is Gjurich's belief that these two methods are superior to the Navy's current process of extrapolating historical trends. He utilized data from over five thousand Officer Master Files (OMFs). Each officer was a Navy Lieutenant (officer pay grade 3/O3) that had already completed his/her initial obligation.

Gjurich found that how well service members perceive their families are being taken care of had the strongest effect upon their retention decision. He also found that ROTC officers were more likely to stay in the service than Naval Academy officers, and that officers with any postgraduate schooling were more prone to stay in the Navy (showing that investing into the personal education of Naval Officers pays off).

One of Gjurich's more interesting points that he made was that the Navy should not be interested in the retention of individuals, but rather should focus on groups of officers; this belief is in line with that of Complex Adaptive Systems (that group behavior is what we are trying to model and understand).

4. Gaupp

Martin P. Gaupp graduated simultaneously with Greg Gjurich (in March 1999), but from the Air Force Institute of Technology (AFIT), which is the major postgraduate institution for the Air Force. It is unfortunate that all four services do not use the same center for their postgraduate course because Gaupp apparently did not know of the retention research being conducted at the NPS by the three previous authors (two of which were aviation specific and therefore applicable to Gaupp's research). As the

Defense Technical Information Center's (DTIC's) database grows and improves, it may alleviate some of these problems.

I found out about Gaupp's research while visiting the AFIT's website, and was able to obtain his thesis and additional materials from Gaupp's thesis advisor, Major Raymond Hill. Since that time, NPS students have been asked to put AFIT on their distribution for all agent-based and retention-based theses. It should also be noted that an AFIT doctorate student (Major Crino) is now considering furthering Gaupp's work.

Gaupp was the first military officer to utilize CAS to study military personnel retention. His thesis is entitled *Pilot Inventory Complex Adaptive System (PICAS): An Artificial Life Approach to Managing Pilot Retention.* When Gaupp started his thesis, the focus of Air Force retention was on pilot retention, as it has been for most of the history of the Air Force. Since October 1998, the Air Force has been expanded its retention concerns to many enlisted specialties [Ref 34, and Ref 49].

Gaupp's model is very specific, developed for one special skill within one branch of the Armed Forces (Air Force Pilots). His goal was to develop an environment that captured the essential information present in the real world (that of Air Force pilots), and then to see what his agent pilots would do retention-wise. The model is limited in how many factors are utilized. The behaviors of pilots are controlled only by how much money they make, and how much time they get off from duty. The environment itself is created by only three factors; those being commercial airline pilot vacancies, the perceived civilian-military pay gap, and the flying OPSTEMPO. Gaupp provides a Java Applet that is utilized to provide the user a graphic user interface (GUI), where the user can manipulate the environmental factors. Gaupp created three basins of attractions,

based upon Chaos Theory (separate, retain, and undecided). It is Gaupp's contention that chaos theory plays a large role in-group behavior.

Gaupp's thesis has the significant challenge that all such theses will have: How do you display what is happening in an un-situated environment. In other words, how do you display something that normally isn't observable? In Roddy and Dickson's October 2000 thesis, they provide an example of how to depict the El Farol Problem (agents choosing whether or not to go to a bar), and Unrath's October 2000 thesis also showed how agents can depict armed helicopter reconnaissance; however, these are situated environments, where one could actually observe these events occurring by standing outside the bar, or sitting inside the helicopter. In the case of un-situated models, the challenge is to try to show users what is going on. Gaupp chose to model his environment after Ariel Dolan's "Artificial Life on the Web, Java A-Life Experiments and Artist 3D Dolls." Please see figure 3.1 for an example of Dolan's A-Life model.

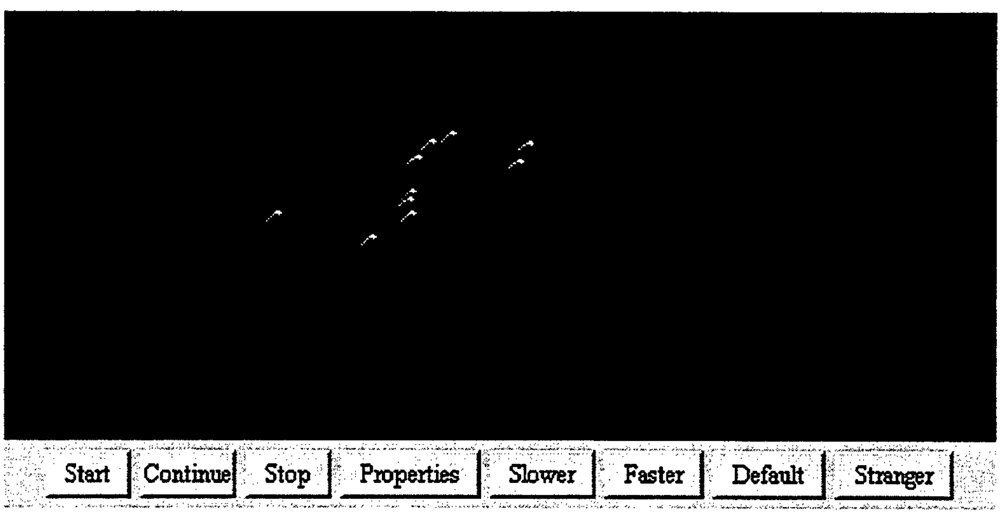

Figure 3.1: Example of Ariel Dolan's Artificial Life Display (from Ref 50)

5. H. E. Mills

Mills studied the difference between two Navy pilot retention programs. Up until 1998, the Navy utilized the Aviation Continuation Pay (ACP) bonus program, which provided bonus monies to target aviator groups. As long as an aviator stayed in he received that bonus. In 1998, the Navy switched to the Aviation Career Continuation Pay (ACCP) program, which tied the bonus monies to specific career positions. As long as aviators continued to advance their careers, they would receive the bonus money. Although the amount of ACCP data available to Mills was limited, his findings are encouraging. Mills found that the new program was causing positive impact upon pilots' likeliness to stay in the Navy, particularly in the crucial years of service (YOS) 11 – 20, which showed an increased likelihood of almost 20 percent. These results indicate that bonus money alone many not gain desired results; we must tie it to events and/or positions.

6. Military Operations Research Society (MORS)

The society is seen as the professional organization for military operations researchers. It maintains a website at www.mors.org. Its last symposium was held in June 1999 at the United States Military Academy (USMA). During this symposium, Working Group 20 (Manpower and Personnel) discussed a number of significant military personnel issues, to include retention. One of the more significant retention papers presented was that of CPT Marty Gaupp's PICAS.

7. William Krebs

Professor William Krebs has done extensive analysis for the Department of Defense over the last decade in the area of forecasting the retention of Naval Aviators. In addition, he served as the thesis advisor for four of the above-mentioned authors (Mills, Gjurich, Bookheimer, and Turner). In 1998, Professor Krebs, along with Professor Samuel Buttrey, and several of their graduate students conducted a retention attitude analysis upon approximately 1700 Navy and Marine Corps pilots [Ref 52]. This research found that aviators are best motivated by high-level needs such as co-worker satisfaction, and job satisfaction. They also found that pay satisfaction was more important for senior officers than junior officers. They further found that retirement pay was significantly more important to retention than was bonus pay (ACP/ACCP), though it should be noted that this study was conducted prior to the repealing of the Redux pay program.

Aviator retention is as significant a problem for the Navy as it is to the Air Force. Figure 3.2 below reflects the retention likelihood found by Professors Krebs and Buttrey during their survey. This survey indicates that all aviator groups have significant retention challenges, with the sole exception of non-flying officers (NFO's) with more than 14 YOS; all other groups have at least 40 percent likelihood of voluntary separation prior to retirement.

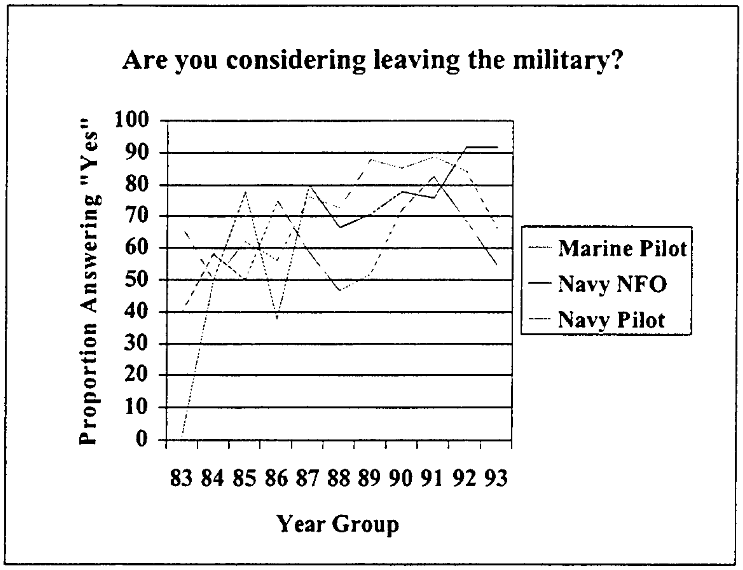

Figure 3.2: Pilots who planned to depart the Navy in 1998 (from Ref 52)

B. COMPLEX ADAPTIVE SYSTEMS RESEARCH

1. John Holland

John Holland is seen by scientists as the father of Complex Adaptive Systems (CAS). He has written several books that discuss the development of Genetic Algorithms (GA) and CAS. In his book *Hidden Order – How Adaptation Builds Complexity* [Ref 4], Holland outlines principles for both CAS and GA, and also demonstrates many of the procedures and approaches for them. These approaches are now being used to study systems in a variety of sciences, to include biological, social, and environmental sciences.

In *Hidden Order*, Holland established a framework for creating MAS that model CAS (based on a cellular schema), which he called Echo. Unfortunately, Echo was built on a now outdated version of C-code. A newer, Java-based, relational architecture has just been released by Roddy and Dickerson, which should be seen as a must-read for all those seeking to create new CAS simulations [Ref 22].

Hidden Order was originally presented as a lecture series at the SFI in 1994. Holland's follow-on book was released in September 1999, and entitled *Emergence – From Chaos to Order* [Ref 5]. In this book, Holland provides further insight into CAS, particularly focusing on emergent behaviors of systems. An underlining theme of this latest book is that complex systems as a whole are more than just the sum of their individual parts.

2. Richard Dawkins

Richard Dawkins is an Oxford-educated author of numerous books about evolution and science. In his book *River out of Eden – A Darwinian View of* Life [Ref 6], he provides outstanding insight for anyone trying to create an agent-based system that will evolve and change over time. Although the book appears to be primarily aimed at biology, readers with an understanding of Holland's GA's can see how it applies to CAS. Dawkins' book does a good job of describing how intra-species natural selection achieves a self-organizing structure. This book describes how organisms evolve over long periods of time (gradualism) rather than through creationism or the leaps and bounds that many scientists often imply in their works. Dawkins states that the organisms interact with each other, and thus form a system that itself evolves over time.

An interesting point that Dawkins makes in this book is about natural selection. Dawkins rightfully points out that it isn't so much the survival of the specific genes, but the survival of the organism that contains the genes. There may very well have been genes that may have given humans far superior skills over what we possess today --- if only their carrier had managed to procreate before he/she died! This leads us to understand that individuals within CAS mutate from time to time; therefore the MAS that

model a CAS should contain a certain amount of random variation (thus modeling mutations).

3. Mitchell Resnick

Resnick works for the Media Laboratory at the Massachusetts Institute of Technology (MIT). His 1997 book entitled *Turtles, Termites, and Traffic Jams: Explorations in Massively Parallel Microworlds* helps to show why Complex Adaptive Systems (CAS) may be the best way to study systems with many moving parts [Ref 7]. In this book, Resnick provides guidance on massive parallelism (the simultaneous processing of large amounts of adaptive agents), which is necessary for running MAS.

Resnick uses conceptual turtles and insects as teaching tools in order to help describe the principles of parallel processing and system self-organization (decentralization). He also attempts to explain why the CAS modeling movement is being resisted (by people having problems understanding decentralization concepts such as bird flock leadership – the flocks have no central leader, but rather each bird takes a turn being the lead bird in order to share the work load). "*Termites*" provides free software for simulating self-organizing system behaviors (StarLogo, based upon Logo, which can be found at the website: www.media.mit.edu/groups/el/projects/starlogo/).

4. Andrew Ilachinski

Andrew Ilachinski is the military's leading researcher in Complex Adaptive Systems. His ISAAC model was the first CAS model designed for modeling land warfare (designed for the Marine Corps). Ilachinski has shown that the collective decentralized interactions among individual agents obeying local rules can often appear disordered at their individual level, but may actually be creating a higher-level pattern of

behavior. Previous land-based war models all used Lanchester equations to calculate losses; the military's field manuals are full of rates that have been developed using these equations (e.g. FM 101-10-1). However, there are many limitations to using these equations for modeling modern combat. Of particular note, they do not take human factors into consideration. Many battles have been won or lost by the beliefs of individuals that spread, and developed into group behaviors that are not predictable by linear equations.

The Civil War battle of Chickamauga is a good example of group behaviors overcoming linear logic. Despite the Confederate Army flanking the Union Army, a small group of individuals, led by General George H. Thomas, created a group dynamic which caused the turn of the battle from a Union defeat, into one of its most important victories of the War. Modern warfare takes this dynamic a further step; warfare is no longer properly characterized by large, homogeneous forces. Today's warfare is better characterized by relatively small groups of highly trained individuals, interacting with an enemy in a constantly changing environment. The future for military operations appears to be continuous OOTW.

ISAAC is set up in an environment that contains the following characteristics that should be further studied for situated environments: A default local-rule set for individual agents; goal directed behavior; sensors that generate an internal map of the environment (a situational awareness) for the individual; an internal adaptive mechanism to alter behaviors. An example of Dr. Ilachinski's ISAAC can be found at figure 3.3.

The ISAAC simulation is a situated environment, playing a version of the "capture the flag" game; two armies compete against each other, with the ultimate army

goal being capturing the enemy flag. Unfortunately, the agents inside of the armies do not always weigh capturing the flag as being more important than surviving. Thus ISAAC is an example of agents that are more than just objects; they may or may not do what they are told (just like real Marines and Soldiers).

ISAAC has an outstanding movement algorithm called the "least penalty function" (LPF), which dictates where agents move on the simulated battlefield. The LPF identifies each possible location where an agent can move, and what is the least painful place to go. If an agent weighs survival more than capturing the flag, then it will not risk its life in order to capture it.

Students at the NPS (under the guidance of Professor John Hiles) created their own versions of the ISAAC simulation, putting focus onto meta-agents (agents with higher level roles such as leadership). The students created local commanders (squad level leaders), and global commanders (leadership who direct junior leaders). The commanders can be played by the user, and have much more information about the battle than the basic agents. In these simulations, agents have to decide on whether or not to follow orders given to them by their commanders. An example of the student-created models (created by Major Jason Stine with the assistance of Major Stevan French, Major Mark Tanner, and Major David LaFlam) can be found at figure 3.4.

A challenge for ISAAC-based simulations is to represent perpetual knowledge derived after the simulation is over. In ISAAC, each simulation stands alone, so the survivors from one simulation do not pass on what they learned to those that conduct the next simulation. However, in a military organization, service members hold after action reports (AAR), in order to learn from their combined experiences. As the members of the

organization rotate out (and new ones come in) the organization still maintains a great deal of the knowledge acquired (organizational knowledge). Thus the unit does not have to re-experience every task again to know what is the best way to complete a mission in a given scenario.

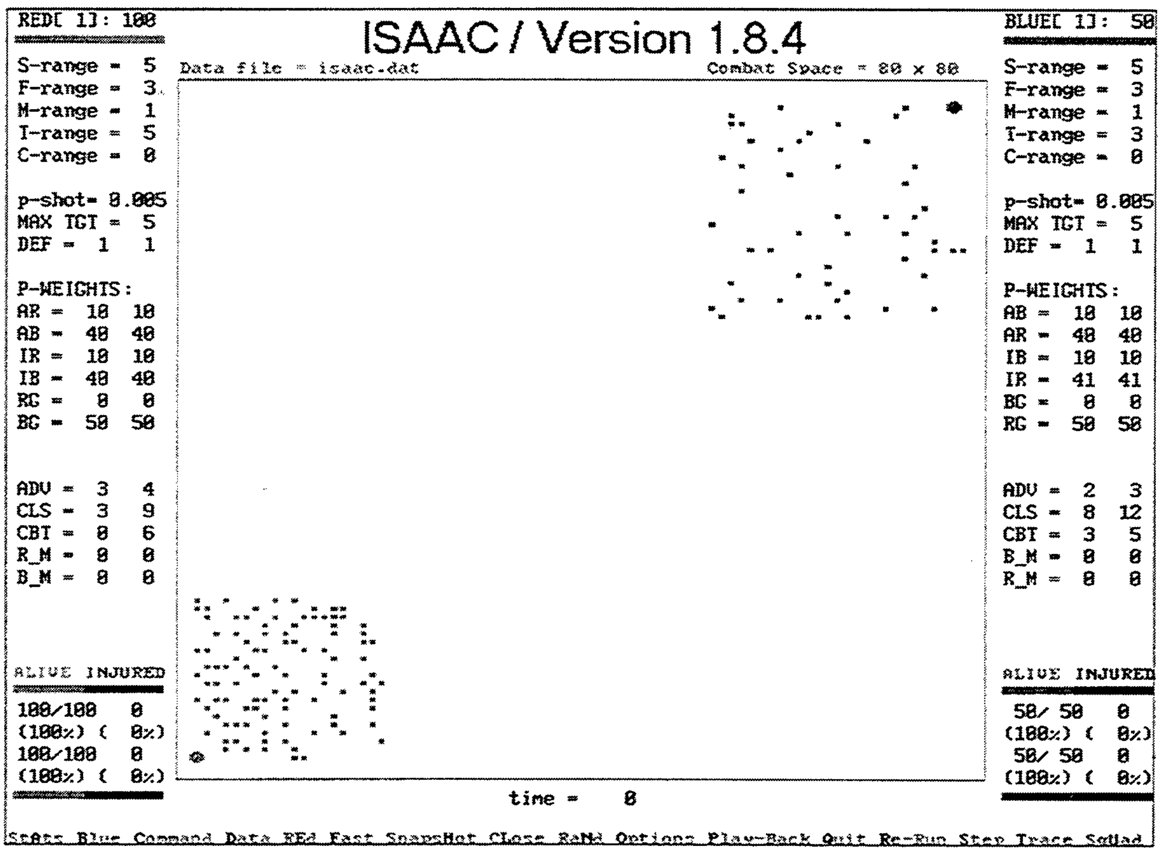

Figure 3.3: Example of Andrew Ilachinski's ISAAC simulation (from Ref 8)

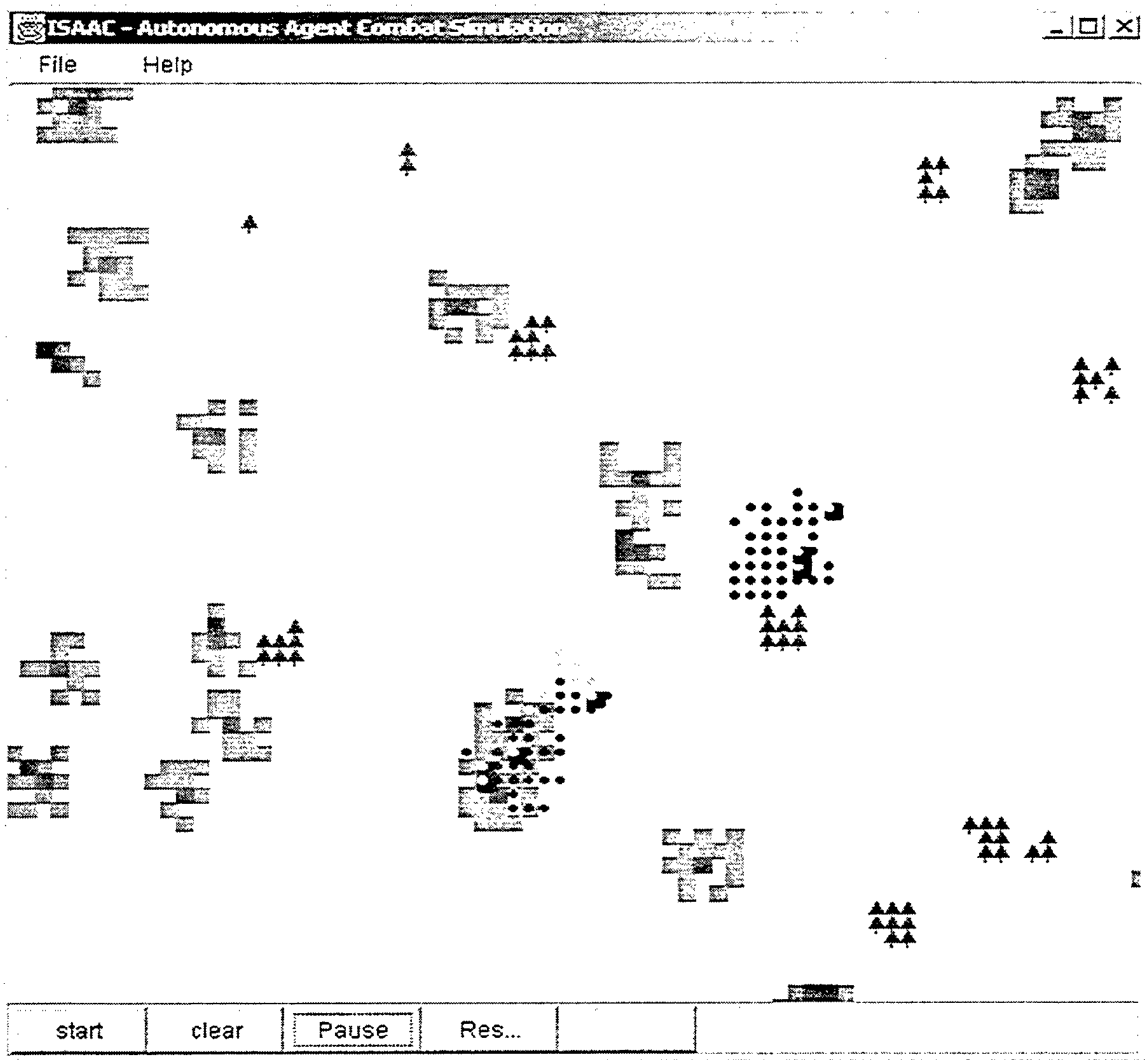

Figure 3.4: Example of NPS Student version of ISAAC Combat Simulation (Stine, French, Tanner, LaFlam)

5. Eric Bonabeau, Guy Theraulaz, and Marco Dorigo

In their book *"From Natural to Artificial Systems,"* the authors detail their studies on the collective behaviors of social insects, and uses the studies to show how to created distributed algorithms, and multi-agent systems in order to derive group behaviors [Ref 11]. Like Resnick, these authors see the decentralized behaviors of social insects as the most appropriate model for evaluating and imitating group behaviors. The authors

believe that social insects have three key features, decentralization, flexibility, and robustness. They define "decentralization" as meaning that decision-making is conducted at the lowest possible level. They define "flexibility" as meaning that adaptation occurs in the environment, but the system continues. They further define "robustness" as the fact that no matter how well or poorly an individual may do its job, the insect colony continues (the failure of one component of the system does not necessarily cause the whole system to fail).

The authors believe that as the world becomes more complex, the top-down simulations we use to model it become increasingly ineffective. However, regardless of how complicated the world becomes, the individuals in it are still the same basic building blocks for society. The authors term the phrase "swarm intelligence" to indicate a system where "autonomy, emergence and distributed functioning replace control, preprogramming and centralization."

6. James Gleick

James Gleick is a science writer, who worked for *The New York Times* in 1987 when he authored his book *"Chaos: Making a New Science"*. Gleick wrote the book to tell about the work of numerous scientists that were trying to find order in what was supposed to be total disorder: Chaos. As computers are able to process data faster, these scientists are able to analyze their data in more depth. Many of these scientists have been able to find complex patterns developing where they previously believed no logic could possibly prevail.

Although Gleick did not know of things such as agents, CAS, or MAS, he did write about multi-disciplinary approaches towards studying systems, and the complex

behaviors that they emitted. Gleick points out that a common theme about the scientist studying chaotic systems is their ability to identify complex patterns where others initially saw nothing. Figure 3.5 shows just one of the many patterns that these scientist have found from chaos (this one was a weather pattern found by Dr. Edward Lonrenz).

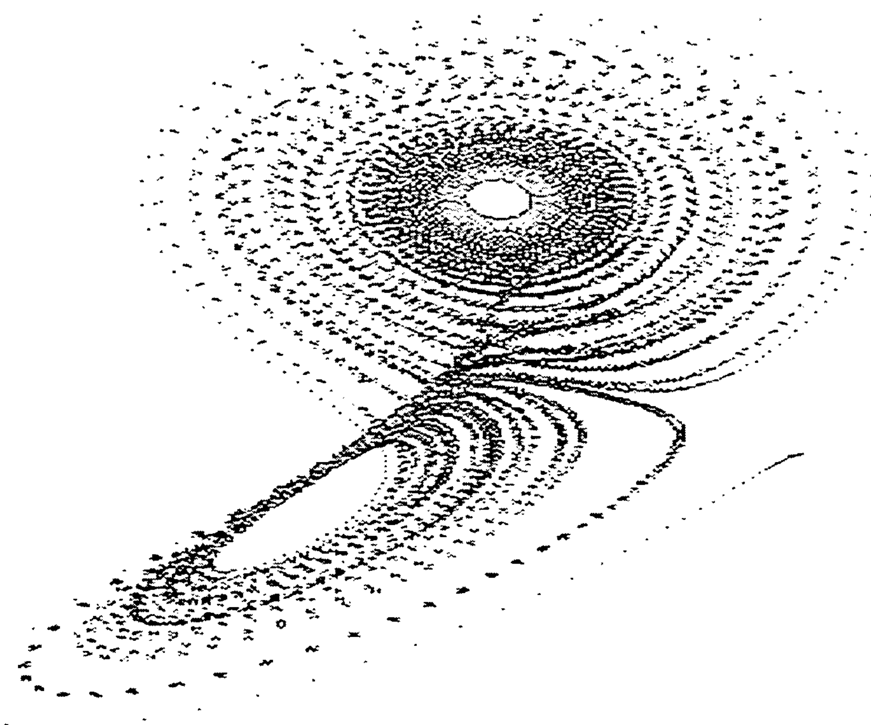

Figure 3.5: Weather Pattern Found by Dr. Edward Lorenz, found in James Gleick's Chaos (from Ref 12)

7. Robert Axelrod

Axelrod is the author of several books on the topic of complexity, to include *"The Evolution of Cooperation"* [Ref 53] and *"The Complexity of Cooperation"* [Ref 54]. Axelrod writes about the social sciences, but he does so from the viewpoint of a computer scientist. "Complexity" contains variations of his most famous computer simulation (that of the story of "The Prisoner's Dilemma"). This agent-based simulation is a series of

identical scenarios between two individuals, each of which can "rat out" the other prisoner, or can keep quiet. If they both keep quiet, they both get a small punishment; if they both talk, they both get more punishment; if only one talks, he goes free, and the other gets a significant amount of punishment (the computer simulation scores the scenario slightly differently). Axelrod's challenge to all programmers is to create a program that will excel at the dilemma over the long run, with random errors thrown in to what the other player is doing. Programs that are too forgiving or too vengeful all seem to lose; Axelrod has found over time (and after many competitions) that it is the agent-based programs that cooperate with each other (including anticipating the errors) that win the game. This includes allowing an opponent to strike back when we accidentally take advantage of them.

8. Natalie Glance and Bernardo Huberman

Glance and Huberman wrote an article for the March 1994 edition of *Scientific American,* in which they introduced a scenario similar to Axelrod's Prisoner's Dilemma, called the "Diner's Dilemma." The article was entitled "The Dynamics of Social Dilemmas." This simulation was more complex though, because there was more than two actors in the simulations, and not all of the actors new everything that was going on. The scenario entailed a group of friends that periodically go to lunch, and instead of getting separate bills, they agree to split the bill evenly each time. This scenario is perfect for agents, as some will try to be gracious, and not order expensive meals, while others will always order the most expensive item on the menu; linear programming would result in all actors playing the game in the same manner.

This simulation also introduces the concept of Metanorms (also used by Axelrod), where actors try to police the actions of other actors. One of the goals of this scenario is to create agent-actors that are able to maximize their gains without being policed. Each simulation always results in one of two states, either many people cooperate with each other, and the system succeeds, or most fail to cooperate, and the system fails.

9. Jacques Ferber

Ferber was the first person to ever attempt to explain multi-agent systems in a textbook format. His book entitled "Multi-Agent Systems: An Introduction to Distributed Artificial Intelligence" was translated from his native French into English, and published in November 1998. It was quickly picked up by professors at the Naval Postgraduate School as being the most concise book from which to teach MAS concepts. In the book, he explains MAS basic principles, organizations, system actions and behaviors, communications, collaborations, and coordination of actions. The most important definitions that Ferber provides are what an agent is, and what a MAS consists of. Ferber's work serves as the backbone of this thesis, and will therefore serve as the source for most in-depth definitions provided in section D of this chapter.

10. Swarm

"Swarm" was originally created by Chris Langton (who would later form the Swarm Corporation of New Mexico). Over the years, Langton has had many people help in the continual development of Swarm, many of who worked for the Santa Fe Institute(SFI) at the time of their work. The best piece of current Swarm work was accomplished by Benedikt Stefansson, who created a tutorial on Swarm in 1999 while he

was at UCLA (that tutorial is still available on the internet at the SFI: www.santafe.edu/projects/swarm/swarmdocs/overbook/overbook.html).

The Swarm tutorial discusses how complex adaptive systems can be created, and appears to be primarily aimed at modeling economics (as one of its goals is to unite those trying to create economic simulations). It describes the main contributions of a Swarm concept as being any of the following: Event Management, Information Management, Graphical User Interfaces (GUIs), Memory Management, and the ability to support multiple software languages. It provides an overview of each of these uses. The briefing also provides an overview of Object Oriented Programming (OOP) for those who may not have had experience with this concept (which allows us to create proper environments for our agents).

Stefansson has just recently furthered his work by publishing a book on Swarm with Fracesco Luna, entitled "*Economic Simulations in Swarm: Agent-Based Modeling and Object Oriented Programming*" [Ref 56]. More information about Swarm can be found at their official website: www.swarm.org/index.html. More information about SFI can be found at: www.santafe.edu.

11. Craig Reynolds

In 1986 Craig Reynolds created the first of his computer models that simulated the flocking behaviors of birds (which he called "Boids"). The model serves as a prime example of how simple rules can often describe what appears to be a complicated system. It also shows that models do not have to be centralized (driven from the top-down), but can often run better and smoother when control is decentralized.

Reynold's initial model utilized three rules: separation (don't get too close), alignment (go in the general direction of all nearby boids), and cohesion (don't get too far away from nearby boids). Each boid is an agent, and runs the set of rules for itself; thus the decisions made by one boid may be entirely different than the decisions made by other boids.

Reynolds has continued to improve his model, to include adding obstacle avoidance. The current model has the birds on the ground, reacting to vehicles driving by them; if a vehicle gets too close, they take a small flight to avoid it; as they continue to get harassed by vehicles, they take longer flights, and cause more and more of their neighbors to react. Reynolds models would eventually be used as the basis for animated group animal behaviors in movies such as the bat swarms in *Batman Returns,* and the wildebeest stampede in *The Lion King.* His work on boids can be found at the website: www.red.com/cwr/boids.html.

12. Georgia Tech University Animation Lab: Group Behaviors

Georgia Tech has some wonderful demonstrations of agent behaviors captured on MPEG's. From bicyclist avoiding road hazards, to one-legged robots hoping around objects, observers are able to see that the individual decisions create group behaviors. The website is: www.cc.gatech.edu/gvu/animation/Areas/group_behavior/group.html.

13. Brian Arthur

Brian Arthur created the El Farol simulation, which is a great tool for both explaining/analyzing agent behaviors, and for teaching beginning agent-based programmers. The basic simulation replicates the behaviors of 100 individuals who all enjoy going to the El Farol Bar in Santa Fe, New Mexico on Tuesday nights. Like most

bars, if it gets too crowded, people do not have a good time; in this case, 60 or more people constitute too crowded. Each patron-agent decides whether or not to go to the bar based upon rules that they are given when they are created (which are different for each agent), and their past experiences of going to the bar.

Each agent makes its decision based upon its heaviest weighted rule (which is called the primary rule); however, all rules are reinforced based upon what would have happened if they had been that primary rule. Over time, poor rules will be discarded, and new rules will be added. Although the agents do not get to talk to each other, at times many agents will utilize the same primary rule. The most interesting phenomena that come out of the El Farol simulation is that the number of agents that actually attend the bar begins to develop a pattern (indicating that the system is not chaotic, but merely operating near chaos).

An example of output from an NPS student version (Major Mark Tanner and Major Stevan French) of the El Farol Problem is found at figure 3.6. The figure appears to start in a state of chaos, until approximately week (simulation) 350, when it appears to be forming a static pattern. This pattern maintains for about 60 weeks, until the simulation slips away from this pattern.

When Major Tanner and I originally began analysis of our El Farol simulations, we stopped at 500 weeks, and were somewhat happy with the patterns we saw. However, we soon began asking ourselves why we should stop at 500 weeks when the simulation did not take a great deal of processing time. We therefore decided to expand the simulation to 2000 weeks and found our results to be more impressive. Figure 3.6 is just one of the many examples we found of the system creating what appeared to be group-

wise decisions about which agents would attend on which weeks. The last 1000+ weeks of this figure reflect a pattern of 31 attendance numbers repeating over 30 times before it eventually went back into a non-static pattern.

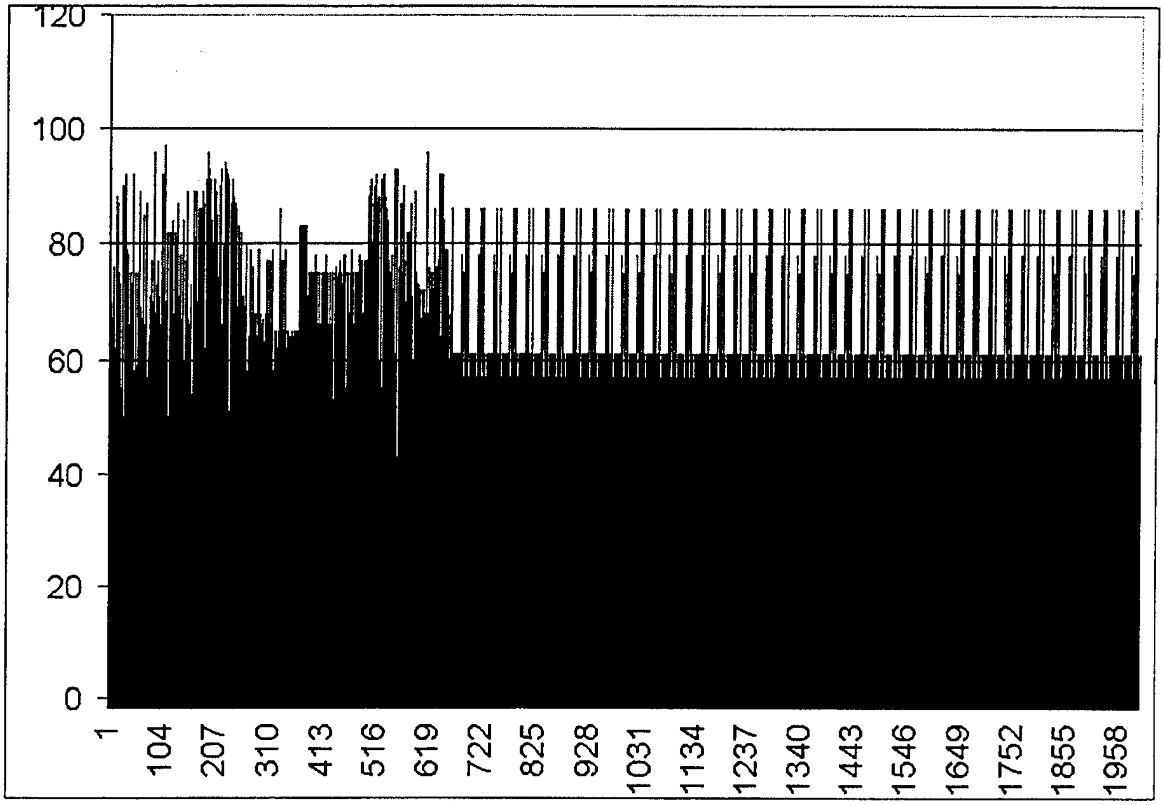

Figure 3.6: El Farol Simulation by Major Stevan French and Major Mark Tanner

C. RELEVANT ARTICLES

During my research, I found a number of articles that should be read by anyone studying agents and/or retention. As these articles will help the reader gain a better overall knowledge about these two areas, I have included synopses on the four articles I have found to be most relevant.

1. An Exploration into Computer Games and Computer Generated Forces

John Laird of the University of Michigan wrote this paper for the Eighth Conference on Computer Generated Forces and Behavior Representation [Ref 57]. In this paper, Laird compared and contrasted computer games (CG's) and computer-generated forces (CGF's). The synopsis is as follows:

Laird wrote about how computer games and computer simulations have improved dramatically over the last five years. He attributes most of this improvement to the increase in available processing speed. This has allowed designers and/or programmers to make more complex environments and objects within those environments. Probably the most important objects within the programs are those that represent players. Inside computer games, we find what Laird terms AI's (which are the computer generated characters that users interact with). Inside computer simulations, we find what Laird terms CGF's (Computer Generated Forces). Both use avatars to represent these interactive objects; in most cases, these avatars are humans, but they can also be pieces of equipment such as ships and planes.

Computer Simulations are the older of the two programming technologies, having been spawned by funding from the Department of Defense. During the Cold War, we needed bigger and better simulations to help with our war planning and preparation. Our government therefore utilized hundreds of millions of dollars into this area. Thus the research that went into CGF's far surpassed that of computer games until after the Cold War was won.

As the technological revolution took off, computer games began an exponential increase in usage and development. AI's therefore began to benefit from the commercial development. Although they still do not meet the standards of their CGF cousins, they are improving at a faster rate than that of AI's. It could very well be that AI's may eventually supersede CGF's in complexity and realism.

Currently, AI's do have several advantages over CGF's. First, their designers and programmers are free to design whatever they want. The final product is whatever it is (designs are subject to change, and are much more flexible than CGF's). CGF designers have to make sure that their products closely replicate human behaviors, and have to worry about negative training effects of any interactions which are not human realistic. A second advantage is that designers are free to select and/or change their standards for their AI's, while CGF designs must follow rigid DoD guidelines. A final advantage is lower cost due to lower requirements.

The main positive for CGF's is that they are scalable and expandable. CGF scenarios are written with few specifics, so that users can create their own scenarios. CGF's are created in mass before any scenario is ever played out. They are then selected, and inserted into a given scenario. On the other hand, AI's must be written to exact scenarios, and normally have to be redesigned from scratch whenever the situation changes.

It should be noted that the goals of CGF's and AI's are orthogonal. The goal of CGF's is to provide realistic training for their users; the focus is on accuracy compared to the real world. CGF's must behave like comparable humans would. CGF simulation may inadvertently be fun to interact with, but enjoyment is not a requirement. AI's are

the exact opposite; the goal is fun, fun, and only fun. With AI's, it is often better if the objects have superhuman powers (especially if the AI is representing the user).

To meet these ends, the AI's are programmed differently than CGF's. While CGF's can only have the information that they have acquired, AI's often have global knowledge about the entire game! This is done so that each AI can best play its role in the scenario that is being run. This is all done for the sake of making the game more interesting for the user. This global knowledge allows the AI's to anticipate what the user is going to do next. This would be next to impossible if the AI's only had local knowledge.

CGF's and AI's fit into game modules differently. The logic that runs CGF's is normally in separate modules than the main program running the given scenario (Laird states that all major DoD simulations have this encapsulation, to include the simulation that he has developed with the Air Force, TacAir-Soar). AI's on the other hand, are often mixed in with the game engine itself. This makes it difficult to separate the AI from the scenario, or the scenario from the game engine (kind of like the Army simulation converted into the kangaroo migration model; when a simulated helicopter flew over, a kangaroo pulled out a rocket launcher and shot down the helicopter!).

The one thing that Laird appears to be focusing in on about AI's is the predictability of most AI's inside of computer games (think embodied, human-like avatars doing the same thing at the same point of every game you play). Laird himself is a computer game designer, and he wants to eliminate this predictability. The cost of predictability is eventual boredom. A game that is the same every time can be fun until it

is mastered, and then it is put on a shelf (or worse, into the garbage). Laird looks to the CGF's as a potential source for solving the problem of predictability.

Development time for the two types of programs differs significantly, thus affecting the complexity of their avatars. Computer simulations normally have several years of development before being used; this allows for the development of complex CGF's. Computer games normally only have 1 year of development time, and thus there is significantly less time for developing the behaviors of AI's. There appears to be a casual affect between development time and usage; the programs that take the most time to develop (computer simulations with their CGF's) normally get used longer. Short, quick, and quick programs (like computer games) take less time to develop, and then are discarded much faster. We should all note that some games (like the Sims) take longer to develop, and provide a higher quality, less predictable product; these games have been known to be used much longer than standard computer games.

Another factor that affects the life cycles of AI's and CGF's is that of reusability. Often times, the AI's are written into a specific game, and are interwoven like Siamese twins. In such cases, programmers will often create the AI's again from scratch rather than try to separate an AI from one game in order to use it for another game.

We should also note that AI's are normally only the creation of one person on a video game project team. This person is usually allocated only 5-10% of the CPU of the computer the game is played on (the rest going to the graphics, networking, sound, game play, physics etc).

AI logic is not normally programmed into computer games in code that maximizes the capabilities of expert systems (like Prolog or Lisp). Instead, the logic is

converted into the native language of the game (C, C++, Java) through conditional statements ("if's", etc.). Preprocessing allows for faster processing of the game. Laird feels that with the ever-increasing speeds of CPUs will usurp any graphics requirements, thus allowing more CPU cycles towards creating more accurate behavior models (AI's). This in turn will allow more complex AI's to be developed.

Laird feels that CGF research could benefit from computer games. First of all, many computer games provide much better detailed environments than computer simulations. Games like Doom are very capable of handling the massive numbers of AI's/CGF's that most simulations need. Second, many games create and provide DLLs which make it possible for networked events to occur, even when all users do not have the source code (a great potential in cost savings). Third, most games are easy to learn, and users are utilizing them almost as quickly as they can open the boxes that the games come in!

In order to better understand computer games, Laird created a simulations that he emplaced into the computer game "Quake II;" he called his AI the Soar "Quakebot." The Soar Quakebot is run on a separate CPU, and interacts with the game using the Quake II interface DLL. Laird uses Socket I/O in order to provide a platform-independent mechanism for transmitting all perception and motor information between the Quakebot and the game.

The Quakebot uses the AI engine that Laird created (Soar). All of the information that the Quakebot needs to play the game is stored inside Soar rules. The game engine is able to interact with Soar up to 10 times a second (for updating information about the

environment and the Quakebot itself). Soar takes between 5-10% of the CPU cycles from its host (400MHz Pentium II running Windows NT).

The Soar Quakebot utilizes principles that Laird learned from other simulations in which he needed to control entities (the latest being a combat pilot simulator). The main purpose of the Soar engine is to make and execute decisions. It utilizes operators (primitive actions, internal actions, or abstract goals) to drive the decisions it makes (all are eventually broken down into primitive actions taken one by one). Final executions are implemented by if-then rules. The Quakebot's long-term knowledge is stored in Rules. The Quakebot also has a working memory that it uses for the current situation. All of this works fine for reacting to current situations.

But how do you deal with what "might happen?" This calls for anticipation. Traditional rule-based systems would say that you should write a rule for every possible situation (like Deep Blue); thus you would have an engine with every possible state (finite-state machine). All you need to do is write in all of the rules. But what about if there are so many rules to process, that you enemy acts before you can anticipate is actions (then you are DEAD!).

Unfortunately, life, and first person shooter (FPS) games do not have a set limit of possible situations. I do not have to move forward, I could simply choose to go backward, or even stay in place! In the case of the Quakebot, it runs on normal rules until it senses an enemy out of weapons range. It then runs an internal program about the enemy in order to determine what it would do if it were the enemy. This program is only run when it senses the enemy, but the enemy cannot be engaged at that time. It predicts what the enemy will do, and then takes its own actions to counter that movement.

After anticipating what the enemy will do, the Quakebot makes a decision on what it will do based upon one of three operators. It simultaneously wants to hunt, ambush, and deny powerups from its enemy. After analyzing the situation, the Quakebot will make the decision that best benefits it. After a given scenario, the Quakebot will "chunk" the situation into a preprocessed decision should the same situation arise again (thus it has completed a form of learning).

The anticipation model can get wrapped around itself. What if the enemy is another Quakebot? Shouldn't the first Quakebot anticipate that the other Quakebot is anticipating it? (Recursion!!!) In Quake, the problem normally doesn't arise, as the first bot to sense the other normally attacks and they both end up simply shooting at each other until one is killed. Another interesting scenario is that not all enemies act alike. Quakebots have got to anticipate that the strategies employed by one type of person may not be the same as others (just like different types of humans fight differently, and lesson we learned all too well in Vietnam). The Quakebot will have to figure out what type of enemy it is facing before it tries to figure out what it will do. The Quakebot model is interesting, but obviously needs to deal with a dynamic situation versus the static one that it is designed to face.

Throughout the paper, Laird talks all around Multi-Agent Systems, but he never uses the term. Laird also avoids using the term "agent," instead using the abbreviation "AI," which is not defined in the paper nor on his website (though he does use AI and agent interchangeably on his website).

2. Pedagogical Agents

W. Lewis Johnson wrote this paper for the Center for Advanced Research in Technology for Education (CARTE), University of Southern California/Information Sciences Institute [Ref 58]. Johnson was a guest speaker at the *Agents 2000* Annual Conference held in Barcelona Spain (and is the Treasurer for the 5th Annual Conference to be held in Montreal, Canada in 2001), and is seen as one of the leading minds in agent research. The synopsis of Johnson's article is as follows:

Autonomous Agents are becoming well known because of their abilities to mimic human behavior. This capability is now being extended in order to train humans in Virtual Environments (VE's). These special types of agents are called "Pedagogical Agents" (PA). These agents are a step above current computer-assisted tutoring systems. PA's go beyond by interacting with students in several different, yet simultaneous modes (multi-modal). These agents are also able to provide feedback to students during training that seems similar to what a student would expect from a human tutor.

One of the best parts of the PA's is that they can be made to look similar to humans, to include gestures and facial expressions. This allows for enhanced communications with humans. This behavior has to be appropriate for the situation at hand, and has to be supported by accurate information being provided by the PA.

PA development has been a science of the 1990's. Part of the focus has been on developing computer programs that act as peers instead of all-knowing instructors. The PA's help versus instruct. PA's must be written to anticipate any type of behaviors from the students or other PA's they may be working with. As humans can be irrational, and do things unexpectedly, the PA's must be prepared to react to just about anything.

Furthermore, the students that they tutor could have anywhere from novice to expert knowledge on the subject at hand; the PA's must be flexible enough to teach at any level. For all of these reasons, PA programs must be robust.

PA's are not just step-by-step instructors. They must be prepared to provide hints on what to do next, or to answer the myriad of "what if" questions that a 3-year old might ask a parent. The PA must therefore have a deeper knowledge of what knowledge encompasses the subject it is tutoring.

The article provides information on several PA's. The first is CARTES' own PA's, STEVE (Soar Training Expert for Virtual Environments) and ADELE (Agent for Distance Learning – Light Edition). Steve is the PA that best represents what many simulations students are currently studying: Training in immersed virtual environments (VE). STEVE an advanced prototype designed to interact with students in networked immersive virtual environments. STEVE's initial tasks included working in VE's that simulated US Navy surface ships. An example of STEVE is found at figure 3.7 below.

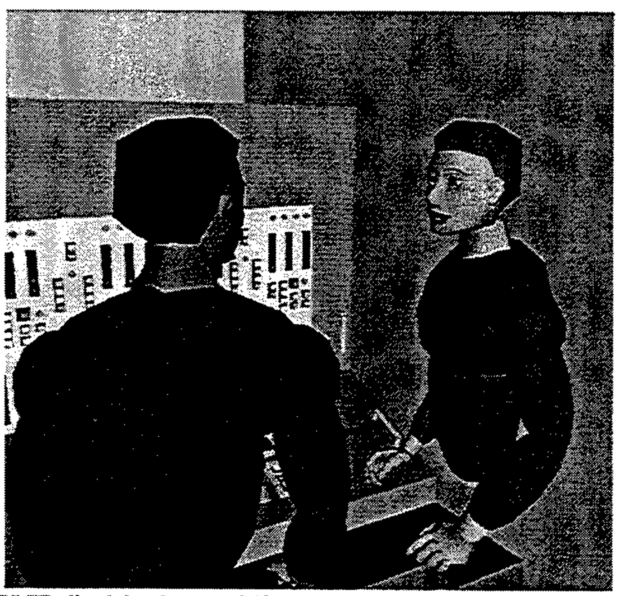

Figure 3.7: STEVE (in blue) providing engineering advice to JACK (from Ref 57)

ADELE is a PA designed for desktop VE's. She is like a high-speed version of the Microsoft Office Assistant, but with a special task in mind: Instructing medical students. ADELE presents medical situations to students, and allows the students to decide what the proper treatment is for the patient.. If the student makes a bad decision, or needs assistance, ADELE interacts with the student. See figure 3.8 for an example of Adele, and figure 3.9 for an example of the many current forms of the Office Assistant.

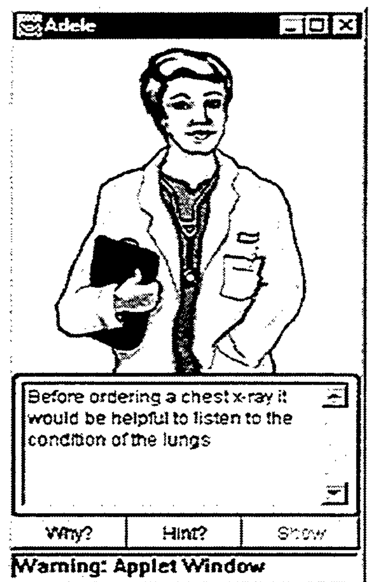

Figure 3.8: Adele offering advice to a medical student (from Ref 57)

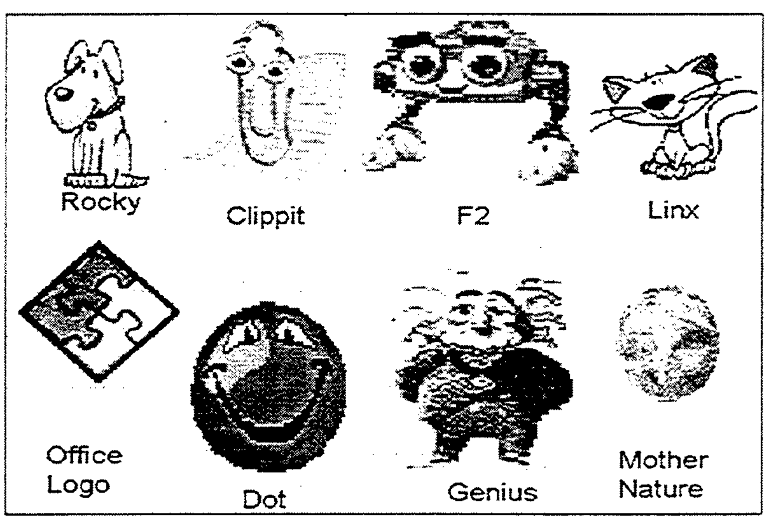

Figure 3.9: The 8 forms of the agent Microsoft Assistant (from MS Office 2000)

There are several other PA's that have been developed. North Carolina State University's Multimedia Laboratory has developed two pedagogical agents: "Herman the Bug," and Cosmo. Herman's purpose is to teach children about plants. Cosmo would be a big assistance for teaching classes on computer networks; Cosmo helps to work out computer network problems. The University of Saarbrucken has also developed a PA that is a super-Paper Clip, called "PPP Persona." This PA helps students get through web-based tutorials in order to enhance their learning and hopefully answer questions that they might have (similar to what a real professor would do in a real class): Thus making professors expendable!

Interactions between PA's and human students can take the full gambit between Microsoft's Office Assistant and STEVE. In order to determine which is best for a given situation, one must analyze the task to determine just how much interaction is needed. If only hints are needed, then the Paper Clip method is probably best; however, if there are many interactions that should take place (or if demonstrations on how a human should execute a task are necessary), then it is best to have a one-on-one instructor such as STEVE.

PA's can also serve as extra humans during collective training. Should a squad of soldiers need to practice a task, STEVE PA's could serve as any missing members of the squad. Thus there could be a squad that is half human, and half PA's. If a baseball player wanted to practice skills at different positions, he could literally have 8 PA's playing the other positions. The player could then move to different positions whenever he wanted to, with PA's filling in each position that he left.

3. Embodiment in Conversational Interfaces: Rea

Justine Cassell is the director of the Gestures and Narrative Language Research Group at MIT's Media Laboratory. Her focus on Embodied Conversational Agents shows the extent to which an agent can be developed in order to interact with humans. A synopsis of her work, published for *ACM* Magazine [Ref 59] in May 2000 is as follows:

Embodied Conversational Characters (ECC) are the logical extension of human – computer interaction (HCI) metaphor. Instead of keyboard input and text-screen output, (or even voice recognition and conversion programs), ECC provide HCI in the form of a two-way flowing conversation. ECC therefore allows for the richness of human-like face-to-face communication, which goes way beyond command-response processing. This technology will eventually allow artificially intelligent tutoring systems to provide actual conversations with students, and real, independent feedback. In order for this human-computer conversation to work, the authors had to properly understand how it is that humans actually communicate with each other. Thus they conducted a Human-Human Conversational Analysis (HHCA).

HHCA describes sets of conversational behaviors that fulfill conversational functions. Conversational functions were broken down into two components, Prepositional (verbal), and Interactional (non-verbal). Dialogues were also broken down into two categories, those being Social (greetings, etc.), and Task-oriented (getting the task completed).

The authors felt that the best mechanism for HCI was the use of human-like avatars, which they call Embodied Conversational Interface Agents. The authors have steadily improved upon their products over the last five years. This progression (in both

papers written, and software products produced) can be seen at the Web Site: gn.www.media.mit.edu/groups/gn/. The first agents were robot-like Avatars that simulated human movements (this was called Body Chat, an example of which can be found at figure 3.10): Later generations made the characters more human-like, with examples being Eddie Edit and Gandalf (both not pictured), two programs designed to help children learn.

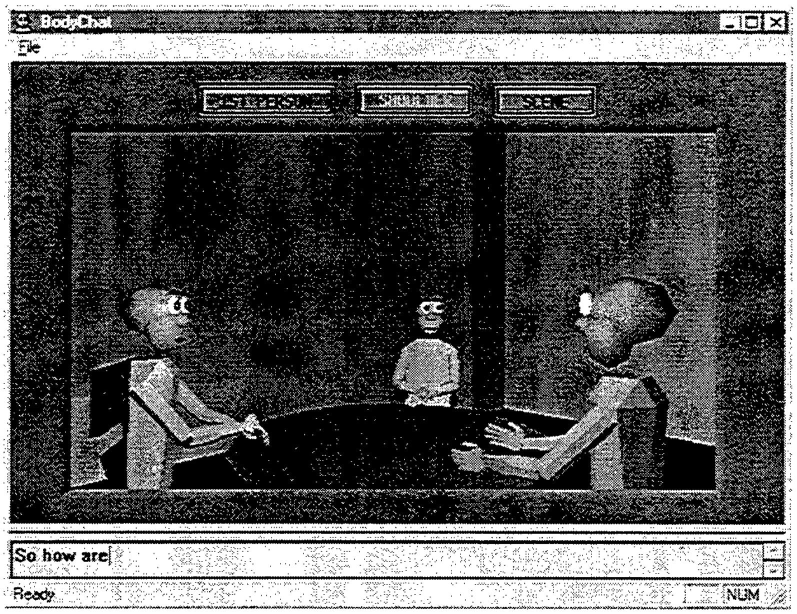

Figure 3.10: Embodied Conversational Agents (from Ref 59)

The latest, greatest generation is a full-bodied autonomous agent created at MIT, called RE (which is short for Real Estate Agent (what "/she" emulates). REA has a fully articulated body, which she uses to send non-verbal cues/ messages to the user. Some examples of this include her turning toward approaching customers, waving and initiating conversations, her raising her hands when she wants to talk, her raising her eyebrows when she wants feedback, and her turning away from users when done.

REA plays the role of a real estate agent because the authors believed that this "job" would provide the necessary range of challenges. Hence REA must interpret and provide both verbal and non-verbal communications, and interact in both a social and task-oriented manner. A picture of REA can be found at figure 3.11.

Figure 3.11: REA greeting customers (from Ref 59)

Many other new software programs are capable of providing output in both verbal and non-verbal manners. A good example of this is Ananova, found at www.ananova.com. Ana provides a number of facial gestures while she "reads" the new through a text-to-voice interpreter. However, most of these programs do not solicit input. Of those that do, they only input text (and only provide canned answers). A picture of Ana can be found at figure 3.12.

REA is superior to these programs because she can input both verbal and non-verbal communications. Rea inputs active and passive inputs through many devices such as user microphones for active input, and cameras aimed at the user for passive input. Rea combines all of these inputs in order to determine what the user is doing, and which

input is the most important. Rea actually synthesizes her responses (including speech and accompanying hand gestures) based on the current grammar, lexicon, and communicative context.

Figure 3.12: Ana "reading" the news (from www.ananova.com)

4. Twitch Speed, Keeping up with Young Workers

This article was written by Marc Prensky, who is the Vice President for Personnel of the Bankers Trust Corporation [Ref 60]. Readers should therefore note that this paper was written by a businessman, and not a researcher. The author is one of many forward-thinking businesspersons that are trying to actively engage his workforce and get the most out of them. While his article does not provide any statistics on what should work, he is able to provide information on what does work (at least in his corporation). The author has been able to incorporate his methodology into a separate business (Corporate Gameware), which provides his software to other corporations for any task that they should desire to be taught. The synopsis is as follows:

Our generation grew up with images being thrown at us at increasing levels of speed. My personal most hated list includes the ads where the camera angle kept changing. This is what advertisers thought we wanted, because it was already a part of our live. Video games change at ranges surpassing 60 images a minute, MTV videos

change even faster (surpassing more than 100 images a minute); action films go even faster. We have not only grown accustomed to these speeds, we have begun to accept these speeds as the standard for our entertainment; anything slower is deemed "dull."

Marc Prensky has rightfully pointed out that although we demand this speed for our entertainment and many other aspects of our lives, we do not demand it in our education. When a person joins a company, they are normally trained in traditional methods. This normally means guest speakers in suits, lulling the new recruits into a comatose state. Industry then began presenting videotapes, often allowing the individual to train at his or her own pace, watching guest speakers in suits.... The author has identified ten of the main cognitive style changes that can be made to improve training, and enhance work production.

a. Dealing with a faster rate of speed

There are very few professions or skills that have incorporated modern speed capabilities into the work environment (pilots, race car drivers, and the like). Some corporations have been created to try to enhance individual worker speeds (such as Evelyn Wood's speed reading), but for the most part, it is the technologies that are increasing in speed, and it is the only requirement of the worker that they be able to mentally process the information being presented to them. Several possible approaches include speeding things up via technology (such as by providing workers with the kinds of real-time data that financial traders use), installing faster infrastructures with fiber-optic cable and T-1 telephone lines, and creating new, MTV-style corporate videos (these work particularly well with young enlisted service members). Re-engineering systems and activities so that things simply move faster is another.

b. You <u>can</u> chew gum and walk at the same time!

Despite what some of our elders told us, it is possible to do two things (or more) at once. While most of our older members of society cannot fathom how someone could get work done with a radio and/TV blaring, most of our generation thrives in such an environment. While it is true that we focus our attention on one source of data input at a time, it is also true that our brain is capable of allowing multiple inputs and processing them all (allocating attention in various orders). Media industry first began to take advantage of this when they began presenting more than one kind of information on video products (think CNN with its ticker tape news at the bottom of the screen). Prensky's main point here is that managers need to take advantage of their workers capacity to take into multiple work inputs simultaneously versus yelling at their workers for doing it on their own!

c. Random versus sequential access to information

Today's generation has grown up being able to have random access to media. It is kind of like our grandparents being able to read the end of the book before reading the beginning and/or middle of the book. There are times when they needed to do such, but normally, the best method was to go through the book sequentially. Prensky's approach is to set up new information-delivery systems, such as corporate intranets, that let workers break out of the traditional boxes in which corporate information has been stored, and then to create tools to link this information to systems that provide logical and decision-making structure. Prensky states that the Intelink, is the best example of this concept. The Intelink is an intranet-based system in which information becomes universally available as quickly as it gets created. This allows

government employees at all levels to access the data they need sequentially, or randomly.

d. A picture says a thousand words

In older generations, you only read books with lots of pictures until you were actually able to read; then you read real books. Now, people are able to process data much quicker with the use of icons (especially when searching for items on the internet). Progressive generations are becoming more comfortable with images, and it could be said that they even prefer them (think about the community information displays found in Hermann Hall and outside the Welcome Center). We are entering an era where it is often best to present pictures until the user is ready for text. Further, we can keep users attention longer if that text is incorporated into graphical displays. Prensky has developed numerous games that actually train their users while they are being entertained. See figure 3.13 for an example of a game trainer.

Figure 3.13: Prensky's Software Trainer mimic of Jeopardy (from Ref 60)

e. A new paradigm for communications

Previous generations communicated information via physical meetings, or telephone calls. These communications were normally unsuccessful should one of the key persons not be available (think about the commercial where nobody knows who called the meeting, or the many times you have played "telephone tag"). People entering today's workforce no longer need to have this connection; we can leave messages for each other (or for anyone in the world) via bulletin boards, chat rooms, emails or voicemails. We could literally carry out a precise conversation and never actually hear each other's voices!

f. Active versus Passive Engagement

Previous generations grew up having to go sequentially through manuals. If you didn't follow bicycle instructions step-by-step, you would fail in the assembly. Current generation users only use the instructions as a last resort. This processing has come about from video games where it was easier (and normally faster) to learn a game through active trial-and-error than through passive engagement. New employees have much less tolerance in the workplace for passive situations such as lectures, corporate classrooms, and even traditional meetings. They are truly the Nike generation of "Just Do It" versus the RTFM ("Read the F---ing Manual") generation.

g. Approaching work as play

Today's generation has grown up on video games. They are used to solving problems in a way that is enjoyable to them. Prensky believes that this generation approaches work in a play like fashion. Successful business comes about from achievement, winning, and beating competitors are all very much part of the ethic

and process. Thus Prensky has tried to link business with video games ("*Business has lots of content, but no engagement; Games have lots of engagement, but no content; if you put the two of them together, you make a new way to learn that makes sense*" --- Quote from Prensky's interview with FastCompany.com.

Prensky has therefore developed a series of 12 software packages that he uses to incorporate corporate training games. The game interfaces look just like many of the games that we use for our daily entertainment. Nobody should forget the photo of the DoD employee of the year (back around 1995), which showed the woman next to her computer, which had an active game of Solitaire displayed. Prensky's games not only include Solitaire, but also Doom and Quake! Prensky's games inject important business subjects into the games, which allow the users to both have fun, and learn about the subject at hand. For example, in the Doom game, the monsters throw problems at the user, and the user has to provide an appropriate solution; if he fails to do so, the user dies!

h. Payoff versus patience

Previous generations always had the proverbial "Gold Watch" as the long-term goals for their careers; they knew that continually performing at a constant rate would yield a satisfactory retirement. Today's generation desires immediate gratification; they want to see the seeds of their performances now, not in 30 years. Many companies have already begun to meet these expectations by providing their employees a "piece of the action," through programs such as "pay-for-performance," stock options, and other equity-like compensations. Companies have also been more apt to provide funding for internal "spin-off" companies, especially when they are internet-based.

i. Fantasy versus Reality

IBM used to be famous for its gray. pinstriped suits. Most corporations had formal attire, and strict guidelines for employee work spaces. While this provided a professional work environment for clients, it stymied how comfortable the employees actually were. Many modern businesses (especially the computer giants like Netscape or Microsoft) allow their employees to set up their workspaces as they desire. They also allow their sections to create fantasy names for themselves, and try to make the work environment as much of a "home-way-from-home" as they can. The end result is that employees tend to voluntarily stay, and work longer hours. The corporations yielding on standards have seen the results of higher work production.

j. Technology being perceived as a friend versus a foe

Previous generations perceive technology as a threat; many lost their jobs due to technological advancements. Generation X changed with technology; generation Y has embraced it. To the younger generation, the computer is a friend, and a companion. Being on the Internet is a part of their lives, and how they communicate with each other.

In this day of scarce employees, young people are getting the opportunity to choose who they want to work for; often times, that selection is not based upon how much money they will make, but rather upon what technology the will be provided. Employers need to understand that putting a young adult in an office without a computer is like taking the proverbial fish out of the water; they will seek out the job that keeps them connected.

For additional information about Twitchspeed, please refer to the following websites: http://www.fastcompany.com/online/17/videogames.html. or http://www.newsweek.com/nw-srv/issue/22_98b/printed/us/bz/bz0622_1.htm

D. CAS CONCEPTS AND DEFINITIONS

The following concepts and definitions come from a variety of sources, though most come from two sources. The primary source is Jacques Ferber's book entitled "Multi-Agent Systems: An Introduction to Distributed Artificial Intelligence." Many researchers, to include the NPS MOVES curriculum see this book as the foundation for agent-based simulations. Ferber released the book in his native language (French) in 1998; and in English in 1999 [Ref 42]. The second significant source is Professor John Hiles of the Naval Postgraduate School. Other sources include Robert Axelrod, John Holland, Brian Arthur, and Andrew Ilachinski.

1. Computerized/Chaotic Object

A computerized object is computer code designed to both store and manipulate information. The object contains variables that store the information that defines/represents the object. The object also contains functions/methods that initialize, change, and retrieve the pieces of information stored in the variables. The functions normally send messages to each other. When objects are agents, the agent-object will have autonomy of action, rich interiors, and random errors that occur in the messages sent between the functions.

2. Artificial Agents (AKA "Agents")

Agents are computerized objects that have the capability to act independently and autonomously. While an agent can operate on its own, it is the interactions between

agents that drive this thesis. The agents socialize with each other, each with its own variable values, and differing goals. Sometimes the agents choose to cooperate with each other, while other times they may choose to compete, or even antagonize each other. There are two types of agents, physical and virtual. The physical agent operates within a simulated copy of the real world; a good example of this is Craig Unrath's helicopter reconnaissance simulator [Ref 61]. The virtual agent operates in an "unsituated" environment, which is one without a counterpart physical environment.

Ferber elaborates that an agent is an entity that:

- is capable of acting in an environment
- can communicate directly with other agents
- is driven by a set of tendencies/goals
- possesses resources of its own
- is capable of perceiving its environment
- has only a partial representation of its environment
- possesses skills and can offer services
- may be able to reproduce itself
- has behaviors which tend toward satisfying its objectives

3. Kenetics

Kenetics, as defined by Jaques Ferber, is the ability to plan, design and create universes or organizations made up of artificial agents which are capable of acting, collaborating in common tasks, communicating, adapting, reproducing, perceiving the environment in which they move and planning their actions to fulfill objectives defined either extrinsically or intrinsically on the basis of a general objective of survival.

Kenetics has the following aims:

- To define a scientific discipline which takes account of interaction between agents as the basis for understanding the functioning and evolution of systems.
- To define the various forms of interaction, such as cooperation, competition, collaboration, obstruction, etc., and link them to the issues of auto-organization, performance, or the survival of the systems.
- To outline the main mechanisms giving rise to auto-organization, such as grouping, specialization, distribution of tasks and resources, coordination of actions, conflict resolution, and so on.
- To define operational models of these interactions by describing the functioning of agents and of multi-agent systems.

4. Complex Adaptive System (CAS)

A CAS is a special living or man–made system comprised of many autonomous sub-components that interact with (and effect) each other, and display changing systematic behaviors. Brian Arthur wrote in his paper entitled "Bounded Rationality" that a CAS is a system whose behaviors fluctuate between the extremes of being rigid (purely linear) and (purely) chaotic [Ref 41].

Over time CAS system behavioral patterns form, leading evaluators to believe that the system can be modeled using standard linear models; however, the behavior pattern will eventually dissipate, displaying behaviors in which traditional modelers would state that no model could ever possibly represent the CAS behavior (e.g. small changes in inputs causing extreme changes in outputs, or a change in one spot having a

ripple affect upon the whole system). One interesting thing to note about any CAS is that despite continuous replacement of components, the CAS will still remain!

Prior to the 1980's, most scientists had the belief that the study of systems displaying chaotic behaviors was futile. Even those scientist who conceptualized that certain systems occasionally formed patterns, were overwhelmed with their complexity, and thus put their study into the "too hard to do" category. However, the technological revolution that began in the 1980's has made it feasible for scientist to now conduct many of these studies due to the tremendous increase in computing power.

Since that time, scientists have found that many systems previously believed to be chaotic were actually just CAS.' Classic studies on CAS now include the study of ant colonies, bees, forests, and Marine combat behaviors! Many scientists now believe that all CAS can now be modeled, and that the best way to do so is with a Multi-Agent System.

5. Multi-Agent System (MAS)

A MAS is a computer program that contains more than one agent inside of a simulated environment. The program provides the environment for the agents to operate in, and interact with, each other. A MAS is different from traditional system programs in that the emphasis is on the interactions between agents, and not on the parts of the system/environment. Analyzing the interactions allows the user to observe systematic emergent behaviors that would never be detected in a top-down systems approach.

Ferber defines a MAS as system that is comprised of the following six sub-elements:

E: An environment that is a space that generally has a volume; this is where the agent exists, and contains the agent's world.

O: A set of objects that are situated within the environment. Basic objects are manipulatable, but not capable of manipulating other objects or the environment. Objects can be perceived, created, destroyed, and modified.

A: An assembly of agents, which are themselves, advanced objects. They are the active entities of the system. --- Agents are objects with intent!

R: An assembly of relations that link objects (and thus agents) to each other.

Ops: An assembly of operations that make it possible for the agents to perceive, produce, consume, transform and manipulate objects.

Operators/Laws: Operators are the world's actions upon objects, and the world's reactions to the actions of agents. Agents also use operators upon objects. Laws are the world's reaction to the agents' operators.

6. MAS studying a CAS

There are three types of MAS studies upon CAS. The first is "Micro-Social Studies,' which is the study of interactions between agents, the forms of interactions, and linkages between agents or objects. The second is "Group Studies," which is the study of processes or organizations that exist within the population (like military retention). The third is "Population Studies," which is the study of the dynamics of large numbers of agents, structures and evolution.

7. Communicating MAS

Often time's agents within a MAS can learn from each other through direct observation of their neighbors (agents located within an agent's sensing range). Additionally, the agents can be designed to send messages directly to each other; in such cases, the agents are called "acquaintances," and the MAS is labeled as a Communicating MAS.

8. Purely Communicating MAS

Purely Communicating MAS (PCMAS) are also known as "un-situated MAS." The acquaintance agents within a PCMAS are also known as "software agents." These MAS do not have synthetic environments that mimic naturally occurring environments. These MAS only have conceptual environments that may or may not be described pictorially. The purpose of these environments is to provide a situation where the acquaintance agents can interact (communicate) with each other. PCMAS are good for modeling systems that rely primarily upon information distribution.

Ferber defines a PCMAS agent as having the following characteristics:

- Exists in an open computing system (assembly of applications, networks, and heterogeneous systems)
- Communicates with other agents
- Driven by a set of its own objectives
- Possesses resources of its own
- Maintains only a partial representation of other agents
- Possesses skills (services) which it can offer to other agents

- Exerts behavior tending towards obtaining its objectives, taking into account the resources and skills available to it and depending on its representations and on the communications it receives.

9. Situated MAS

A situated MAS (SMAS) is a multi-agent system whose agents are positioned in a synthetic environment. SMAS are models of systems whose components actually exist in physical space. If a STEVE simulation had several agents operating together, it would be a good example of a Situated MAS.

10. Purely Situated MAS

A purely situated MAS (PSMAS) is a situated MAS in which the agents do not communicate by sending messages but only by the propagation of signals. The PSMAS contains agents that represent physical entities, which are called purely situated agents.

Ferber describes purely situated agents as having the following characteristics:

- Is a physical entity or simulated computing entity
- Is situated in an environment
- Is driven by a survival/satisfaction function
- Possesses resources of its own
- Is capable of a limited perception of its environment
- Has practically no representation of its environment
- Possesses skills
- Can reproduce/pass on its traits to other follow-on agents
- Behaves with a tendency that fulfills its survival/satisfaction function, taking into account the resources, perceptions, and skills available to it

11. Environments

For situated MAS, the environment is a physical space or simulation of a physical space. The agents within the environment are capable of perceiving the environment, objects within the environment, and some of the other agents that also live in the environment. The agents are capable of manipulating each other, and the objects within the environment. The net result of all manipulations is the changing of the environment itself. When the MAS environment is changeable, it is called a reactive MAS.

12. Levels of Organization

Ferber describes three levels of MAS organization, the Micro-Social Level, the Group Level, and the Global Society Level. The purpose of Micro-Social Level MAS is the study of the interactions between agents, and of the relationships that form between pairs or groups of agents. The purpose of Group Level MAS is the study of organizations, and the role/relationships that form/emerge from within the organization. The purpose of Global Society Level MAS is the study of large numbers of agents, their interaction with the environment, and the environmental evolution that occurs.

13. Emergence

Emergence is the property of evolving MAS. It is the behavior that the environment exudes due to the interactions of the agents with other agents, objects, and the environment itself. The emergent properties of MAS often result in the whole system being greater than the sum of its parts. MAS Systematic output is often studied to determine whether emergent behaviors forms from the component agents collective behaviors.

14. Cognitive Agents

Cognitive agents (CA) are agents that have goals and explicit plans which allow them to achieve those goals. In comparison to reactive agents, CA are considered to be the more sophisticated agents; this is because they have considerably more information storage and functionality which allow them to operate independently of other agents. There are two principle types of cognitive agents, "intentional agents," and "module-based agents."

a. Intentional Agents

Intentional Agents are the predominant type of CA. Their name implies that they have explicit goals that motivate their actions (thus everything they do is intentional). They are also referred to as "rational agents" because the intelligent and intentional actions they take are normally seen as rational steps towards achieving their internal goals.

b. Module-Based Agents

Module-based agents are also known as "reflex cognitive agents." Although they are agents themselves, they provide a secondary mission within MAS, and are seen as aides to the primary agents. Their sole purpose for existence in MAS is to provide information to the primary agents, or to provide a specific interaction with the primary agents. Module-based agents are perhaps the agents most closely associated with basic objects.

15. Reactive Agents

Reactive agents (RA) are less sophisticated than cognitive agent because they are intentionally designed to have limited capabilities in the areas of data storage, and

functionality. These limitations cause RA's to be cautious in their decision-making. Thus RA's do not plan out what they will do in the future; they simply react to significant events that occur to them and their environment. The limitations also cause the RA's to interact with each other in order for each to develop better environmental and situational awareness (while each RA only has limited knowledge, collectively they have considerable knowledge).

It is important to note that while CA can operate independently, RA's need acquaintances. Thus the behaviors that emerge from RA's are truly systematic, and not individual behaviors from specific agents. RA's are sub-divided into two main categories, "drive-based agents," and "tropistic agents."

a. Drive-Based Agents

Drive-based agents react to specific events occurring within their environment. These reactions are in accordance with one or more rules that are designed to achieve specific goals for each agent (rules will be different from agent to agent). If no events are occurring, the agents typically remain in an unchanging state. Drive-based agents have what is called "hysteretic memory;" this means that the agent is capable of remembering what has happened before (and thus it remembers how it reacted to a situation before, and whether or not that reaction was appropriate).

b. Tropistic Agents

Tropistic agents are reactive agents that continually respond to the stimuli coming from within their environment. Their decisions are based purely upon the current state of the environment, and thus their decisions will continue to be the same until something changes the environment. Events do not have direct effects upon tropistic

agents; their only effects are those that occur indirectly through manipulation of the environment. These agents have (appropriately named) "tropistic memory," which means that they do not remember situations from the past, how they reacted to those situations, or if the previous decisions it made were appropriate --- they simply react to stimuli.

16. Interaction

Interaction is the process of agents dealing with other agents (to include module-based agents). The agents learn from each other, and also influence the decisions that each may make in the future. Some interactions result in positive influences, while others result in negative influences, or in neutral influence. Interactions also allow agents to develop and learn about their environment from each other. This learning allows the agents to do more than they could have by themselves. While each agent develops on a personal level, the system as a whole changes, emerging into a new state.

17. Adaptation

Adaptation is the process whereby an organism fits itself into its environment. There are two different levels of adaptation, individual and systematic. Individual adaptation occurs when an individual agent changes itself in response to feedback that it receives from its peers and/or environment. Like humans, the agent learns over time, and adapts how it conducts itself. Some agents will learn to be successful in their environment, while others will not.

Systematic adaptation is similar to the adaptation of living organisms (as discussed by Richard Dawkins [Ref 6]). However, in this case, the adaptation must be driven by a routine within the synthetic environment. The routine evaluates the success

of each agent, and the traits that those agents possess. The routine then creates replacement and/or additional agents with combinations of the most successful traits. The routine may also throw in random variations of traits in order to include the concept of mutation into the MAS.

18. Agents Abilities

Each agent will have differing levels of the following agent properties:

- Action: Able to modify their environment
- Communicate: Signals or messages between agents
- Intention: Intrinsic or autonomous
- Resources: The wherewithal to take action
- Partial Knowledge: Point of view; they know about some of the world they are in (not all, not none)
- Capability: Skills and services
- Feedback: Persistence and sometimes reproduction.
- Reproduce: Ability to create follow-on agents (though not always)

19. Agent Domains

Each agent has its' own domain. It may also belong to a larger domain, or may even belong to several levels of domains. Each domain may direct the agent to have a different "intent." The agent wants what satisfies its needs, but it may belong to other domains that call for it to satisfy external needs (of those domains). The end result may be that the agent's behaviors work towards satisfying all or none of these needs.

20. Agent Knowledge

Normally, agent-objects only have partial knowledge of their environments. This allows them to grow and learn from each other. In general, agent knowledge is based upon what it has encountered, and what it has tried to do itself. What an agent believes to be true may or may not be what is globally/absolutely true. In MAS, global knowledge is generally considered god-like; thus perfect knowledge within a system is normally only associated with external observers.

21. Stimulus – Response (S-R)

Stimuli cause responses in an agent, and are thus the events that cause learning. If the agent benefited from the response, the S-R is "positively reinforced," if not, it is "negatively reinforced" (Encoding). Multiple stimuli can hit an agent at the same time (often the same stimuli hitting different senses).

22. Credit Assignment

Credit assignment is the process by which an agent awards or punishes its internal rules (raises or lowers the value of that specific rule). If a rule allows the agent to take advantage of a good situation, then it is rewarded. If a rule stops an agent from taking that advantage, it is punished. If a rule causes an agent to take a bad action, it is punished. If a rule stops the agent from taking a bad action, it is rewarded. Over time, the agent will rely most heavily upon the rules with the highest values/weights. A good example of this rule system is that of a frog. If a rule says to eat a fly, it is rewarded. If the rule says do not eat the fly, it is punished (the frog didn't get to eat a good meal). If the rule says eat a bumblebee (and the frog gets stung), the rule is punished. If the rule says not to eat the bumblebee, it is rewarded (for protecting the frog from pain).

23. Genetic Algorithms (GA)

Genetic Algorithms are formulas for MAS that reproduce agents based upon previous "parent" agents. These MAS take the most successful traits from current agents, and base them as the foundation for future agents. The three basic types of selection are creation (e.g. by God), random, and natural (letting nature take its course). The key mechanisms for GA are crossover (genes mixing), inversion (mutation), and chromosomes (Predictors). The chromosomes are packages containing many (at least two) genes/rules (called "alleles"). Thus offspring receive chromosomes with genes from their parents, some of which may have been altered via the key mechanisms. The representation of rules in the new generation is roughly proportional to the success that they had in the previous generation. The result is the creation of a new set of agents, most filled with successful combinations of rules, and occasionally some (.01% to .001%) with new combinations of previously successful rules. This allows the successful solutions (and derivatives of them) to continue, while less successful ones die out.

24. Goals and Rules

Goals are what each agent is trying to accomplish. In situated MAS like ISAAC, they include such things as advancing, or capturing the enemy flag. In unsituated MAS, they may include maximizing happiness, or obtaining the lowest price. Actions are the means by which agents attempt to achieve their goals. Examples of actions include the situated actions of taking the shortest route/safest route, and the unsituated actions of avoiding confrontations, or interacting with as many seller-agents as possible. Quite often, the current conditions within an environment will have a significant impact upon what actions an agent will take.

Goals must be measurable in order to see if they have been achieved. Goal measurements may be absolute, or have intermediate measurements. One of the best ways to determine whether a goal has succeeded or not, is to introduce feedback into the model. An example of this is intermediate commander agents reporting back information to global commander agents.

25. Relationships

Relationships form organizations. In the case of retention, each servicemember agent has relationships with his/her family, peers, mentors, and its chain of command. Thus the relationships are the connections between agents. Each relationship will have different roles. To family agents, the servicemember agent is a father/mother; to peers, the role will be that of friend; to the chain of command, the servicemember agent may be both a leader and a follower. Each relationship may cause an agent to change its goals. Relationships can change over time, thus affecting an agent's goals.

A good example of changing goals is that of a single servicemember who gets married and then has children. This agent has added roles, which may or may not affect his/her behavior. The amount that roles affect behavior is based upon the weight that the agent applies to that specific role. The primary job of wartime leaders is often convincing servicemembers to weigh their role as protectors of our country more than they weigh their other roles, and life itself.

26. Malevolent Agents (MalAgs)

Malevolent Agents are agents that are thrown into MAS for the explicit purpose of causing the primary agents to deal with turmoil. MalAlgs may not always be observable by the primary agents, and may wait until crucial moments in a scenario

before they unleash their harmful effects. Utilizing MalAgs ensures that agents and humans (in the loop) plan for the worst possible scenarios occurring (Murphy's Law).

27. Mobile Agents (AKA Aglets)

Mobile agents are agents that transport themselves from one computer system to another. These agents are very specialized, and have specific missions given to them by their "owners," such as seeking out the best airfare for a vacation trip, or finding new parts for an aging computer. Aglets from various owners therefore meet and negotiate business in cyberspace (anywhere from within a local area network (LAN) to the Internet itself). The aglets thus allow their owners to concentrate on other business. The aglet negotiations are somewhat similar to what their owners would do; each negotiates within a given set of parameters, and either come to an agreement, or choose to do business elsewhere (routing themselves dynamically). Each aglet keeps its goals secret from other agents so that they cannot be taken advantage of by the other aglets. Once a mobile agent makes an agreement (or after it has met its maximum search time), it reports back to its owner.

Aglets communicate by sending messages to each other. The method is called a "push and pull scheme. Pushing occurs when an aglet wants to get something from another aglet. Pulling occurs when the other aglet wants something from the first agent. The environment surrounding the negotiations is called a "place."

Aglets have many advantages over traditional programs. Some of the advantages are that they reduce the overall network load, can overcome network latency, encapsulate protocols, are adaptive, and are robust.

E. SUMMARY

The Department of Defense has an increased challenge in analyzing Military Personnel Retention during times of continuous change. The Technological Revolution and US economic boom have jointly created such an unstable environment here at the start of the 21st Century. Current linear retention models are proving less than optimal, as the Services continue to be caught off guard by extreme changes in service member retention behavior. The military therefore needs new models to help deal with the paradigms it is now facing.

Although technological advances are partially to blame for the current retention situation, they can also be used to help adapt and overcome the crisis. One of the major benefits of the Technological Revolution is the great increase in computer processing speeds. This advancement has made possible the study of complex system behaviors previously thought to be too complex for modeling. Many scientists are now finding order in systems previously believed to be purely chaotic.

Researchers have begun to utilize MAS for military research purposes. Andrew Ilachinski has led the research through his ISAAC simulations. A number of military officers have begun to utilize MAS for their thesis research, to include one on military retention (Gaupp's afore-mentioned PICAS simulation for Air Force aviators).

CAS terminology can be complex, and confusing. As this research field is relatively new, different researchers may call the same things by different names. Jacques Ferber is the first researcher/professor to release a book that detailed key

CAS/MAS terminology and concepts. Ferber's book on MAS is seen by the NPS as the most complete and comprehensive source on CAS/MAS.

This thesis is a merger of the previous research analyzed in the areas of Military Personnel Retention and Complex Adaptive Systems. The author believes that the literature researched provides an adequate foundation for the creation of a military personnel retention simulator capable of simulating any military occupation specialty within the Armed Forces.

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IV. MODEL DEVELOPMENT

"Nothing goes by luck in composition. It allows for no tricks. The best you can write will be the best you are." --- *Henry David Thoreau*

A. FILE HEIRARCHY

There are twelve significant java files used in the MPRS project. Three of the files (MPRS, Simulation, and Environment) are the code that drive the simulation and provide the environment for the agents to operate in (the MPRS file creates Simulations which in turn create the Environment in which the agents operate). Four additional files (MOS Setting Editor, Simulation About Box, Agent Dialog and Environment Dialog) provide the user with the opportunity to fine tune simulations by adjusting parameter values. One file (Data) is a storage class used to pass information between the driver files. The remaining four files (Agent, Spouse, Child, and Civilian Friend) are all agent classes that represent service members, the families, and friends. It should be noted that the service member agents also play the roles as mentors and military friends to other service member agents.

B. FILE DESCRIPTIONS

Each of the twelve java files named above serves a different purpose within the MPRS simulator. The following summaries briefly describe each of the files, and its purpose.

1. MPRS

This is the main MPRS executable file. It determines whether the user wishes to run a demonstration or a user-defined simulation through a series of Java dialog boxes. If

the user desires to set his/her own parameters, this file extracts that information and inserts it into the simulation. Data passed between files is stored in a storage "Data" object. Regardless of the type of simulation run, this file creates the appropriate operating environment, and then executes the simulation. Once the simulation is complete, this program determines whether or not the user wants to run another demonstration, his/her own simulation, or to shut down the program.

2. Simulation

The Simulation class determines what branch of service the user wants to emulate, and then creates the frame that will contain the simulation during its execution. It then creates an environment object, and adds it to the simulation. Simulation is also the file that determines what the user wants to do whenever he/she clicks on the main MPRS panel. In particular, Simulation is responsible for taking action whenever the user clicks on the control buttons (start, pause, resume, clear, and environment controls). When one of these buttons is clicked upon, Simulation takes the appropriate action.

3. Environment

This is the environment in which the servicemen agents "live." As this is an unsituated simulation, there is no physical environment. All agents therefore exist in this communications space (which is made to look like the life-cycle of a service member careers for users to observe what the agents are doing). Environment creates all of the various types of agents, and assigns service member agents their mentors, friends, and families (the make-up and number of family members being driven by random generations based upon the information contained in the Data object passed into it). Each agent is represented by a filled in oval, which is colored to reflect the rank of the agent.

The vertical location of the agent depicts how happy they are with their careers (the higher up on the panel they are, the happier they are; the unhappier they are, the lower they are on the panel.

If agents get too unhappy, and are at a point where they can choose to get out, they will do so by resigning/ETSing (Expiration of Time in Service), either of which is signified by the service member agent exploding into a red ball of fire at the bottom of the panel). This is the problem that the military is trying to avoid (we do not want service members choosing to depart the service). As time goes by, the agents will move from the left side of the panel to the right, signifying time elapsing (each simulation step is equivalent to one month of a service member's career).

When the agents come upon solid vertical lines, it is time for them to be considered for promotion. Environment selects agents for promotion based upon their previous job performance (total scores from the evaluations that they receive each year). Agents with the best ratings are promoted (which may or may not be reflected by their location on the panel). Agents that are not promoted get passed over (which is also reflected by their exploding into a red ball of fire). If too many service members choose to get out on their own, all remaining service members will be promoted (which is not what the military wants).

Environment represents time one month at a time by moving all of the agents three pixels to the right. It tracks agents until they depart the service, or have 22 years time in service (at which time it removes the agents from the simulation). Agent happiness can be determined based upon their location on the panel. A dotted horizontal line depicts average happiness; agents above that line are happy, with those below it

being unhappy. Agent "inclination" (direction their happiness is going) is determined by the slope depicted by the direction that each agent takes. Clicking on a given agent will bring up a data box about that agent, which includes information about the inclination.

When an Environment creates its agents, it emplaces them into a vector called the "Agent Vector." Whenever an agent departs the service, it is moved into a second vector called the "ACAP (Army Career and Alumni Program) Vector." At the conclusion of the simulation, information is extracted from the agents in the ACAP vector, and then provided to the user on the DOS Command Line. This data should be transferred to a statistics package such as S-Plus or MS Excel for analysis.

4. MOS Setting Editor

This class creates a dialog box that allows the user to edit the parameters being used in the simulation. The user is provided the dialog box just before the simulation is executed. The user is shown the current settings that will be used should he/she choose not to make any changes. This is done by extracting the values currently stored in the Data object (that will be sent into the simulation). If the user chooses to change the parameter values, he/she need only type over the current settings. When the user hits the "okay" button, the parameter values are sent back to the Data object (over-writing the old values contained there).

5. Simulation About Box

This AboutBox is based upon an AboutBox created by LT Mike Dickson (who used JBuilder3 to create his version). This file simply allows the user to receive MPRS development information whenever they select the appropriate menu bar item from the top of the MPRS panel. When selected, the user is provided with information pertaining

to who created the MPRS, and what version it is in. This allows multiple users to ensure that they are both using the same version of the MPRS. After June 2001, updates of the MPRS will be available at the website www.familyfrench.net.

6. Agent Dialog

The Agent Dialog Box is used to display all pertinent information about a specific service member agent. It is activated by either left or right clicking onto a specific agent on the MPRS panel (it is easiest to do this after hitting the "pause" button). When an agent is selected, that agent's dialog box will appear (an example of the Agent Dialog Box can be found below at figure 4.1). All information presented is extracted from the data fields within the service member agent objects.

The dialog box is broken down into four main areas: Agent Data, Career Data, Family Data, and Agent Attitude.

- The Agent Data section provides information about the selected service member agent. It states the agent's number, its rank/pay grade, its color (which graphically represents its rank), its fictitious social security number, and its military occupation skill (MOS).
- The Career Data section provides the user information about the career success that the agent is having up to this point in the simulation. In addition to branch of service and career path (officer/warrant officer /enlisted), this area tells the user what year group the agent belongs to (what year it started its career), how long it has been in the service, how long it has been at its current rank, and most importantly, what its evaluation reports have been like up to this point in its career.

Center of Mass (COM) means that the agent is having an average career; above COM (ACOM) means that the agent is having a superb career; below COM (BCOM) means that the service member is having a poor career. When agents come up for promotion, their ratings will determine who gets promoted, and who gets put out of the service (it should be noted that if too many service members choose to get out of the service on their own, then all remaining agents will be promoted).

- The Family Data section provides information about the service member agent that may have considerable impact upon whether it opts to get out of the service or not (the agent's family). This section shows the user the marriage status of the agent, and how many total dependents the agent has (these numbers are based upon information provided into the simulation by the user; random numbers determine which agents have which types of families). Each family member is an actual agent (though module-based), whose happiness level affects the happiness of his or her service member agent.
- The last section depicts the Agent Attitude. The attitude of a service member agent is determined by its family, career, and the environment. The section depicts current satisfaction (how happy the service member agent is), and also the inclination of that happiness (is it getting better or worse?). As in real life, an improvement in any of these areas may result in a positive effect upon the service member agent.

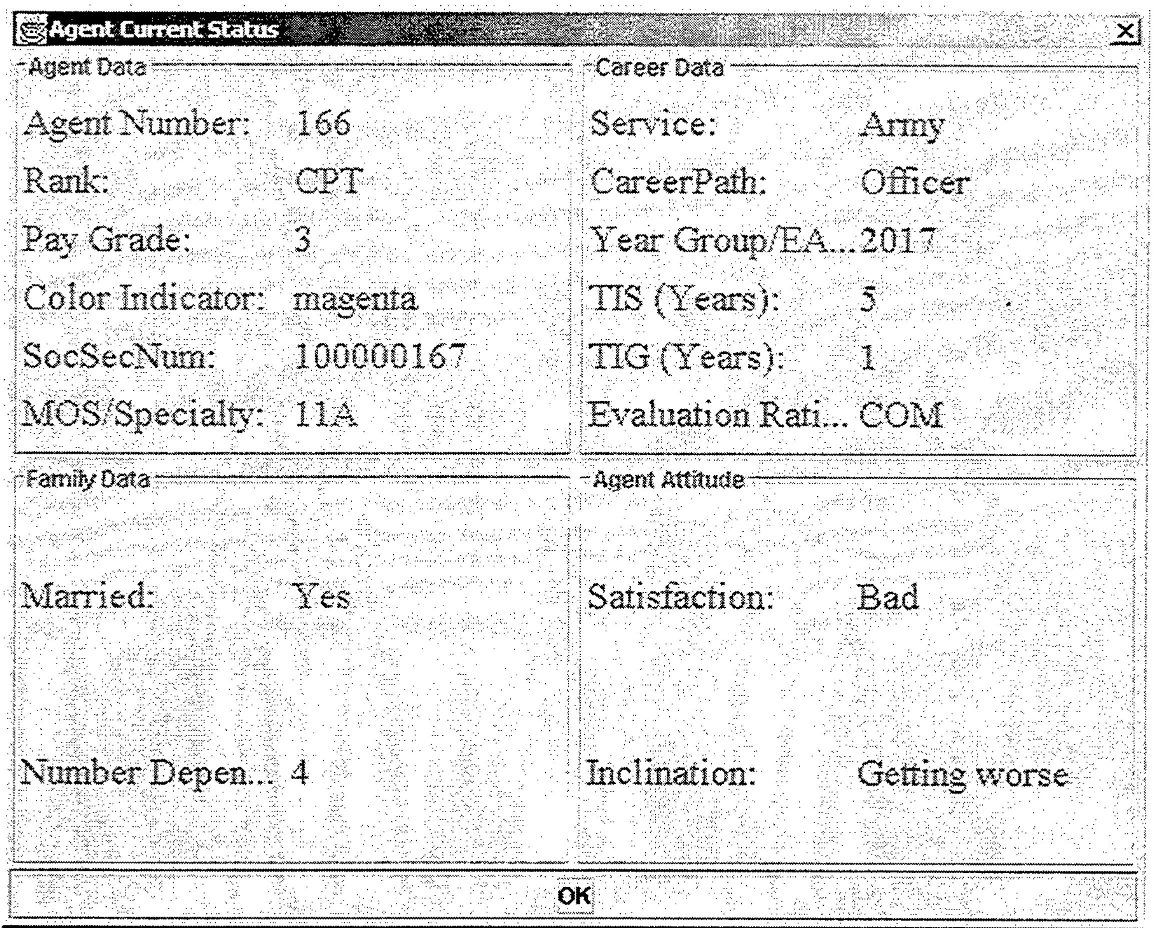

Figure 4.1: Agent Dialog Box Example

7. Environment Dialog

This Dialog is instantiated by the user clicking on the "Environment Controls" button on the MPRS panel. The dialog is how the user changes the major environment-wide factors that affect the everyday lives of the agent servicemembers. The settings include the perceived Chain of Command concern, the perceived Department of Defense concern, the perceived civilian-military pay gap, and the perceived Operations Tempo. All of these factors are prefaced with "perceived" because it is perception that drives servicemembers' beliefs about reality. These factors should all be set based upon current perceptions within the applicable area being studied.

All four factors start of as being neutral/average. Each factor has a slider bar that enables the user to change the values. NOTE: The values can be changed while the simulation is running; however, users should make in-run changes only to see that the changes take effect immediately. If the user would like to compare runs at different settings, the user should make changes prior to starting the simulation run (and allow each simulation to complete its run without mid-cycle manipulations).

8. Data

This class is a data storage class used by the main files to store numerous parameter values. The data object is then sent between the files as one large parameter, allowing ease of use, and readability by the user. Only one Data object is used in any given time. Methods inside the class consist primarily of "getter" and "setter" methods for manipulating the parameters stored within the object.

9. Agent

Agent is the file that actually completes the service member agents when the Environment Class "creates" them. These agents are the key objects in the simulation as they represent individuals and their decision-making. Each agent contains all of the personnel information necessary to manage its career. The agent keeps track of its rank, years of service, time at its current rank, time obligations to the service, how happy it is with the service, and whether it is getting happier or unhappier (inclination). The agent also keeps track of how many family members it has, and takes the happiness of those family agents into consideration when determining its own happiness levels. Each service member agent also has a senior agent as a mentor, military friends (other service member agents), and civilian friend agents. As with family members, each service

member agent takes all of these other agents' happiness levels into consideration when they evaluation their own happiness level.

If an agent gets out of the service, it remains actively engaged with all other service member agents that it has relationships with (that are still in the simulation). If the service member agent finds happiness outside of the military, it will negatively affect the happiness of his service member agents that are still in the military; if such an agent does not find happiness as a civilian, it positively affects its service member agent friends still in the military.

When an agent retires or gets out on its own accord (ETS/Resignation), it stores all of the information about why it got out (data such as its unhappiness level, years of service, pay grade, and family situation). That information is extracted upon the completion of the simulation, and is provided to the user for analysis via the DOS Command Line.

10. Spouse

The role of the spouse in this simulation is simply to affect the service member agent like a real spouse would affect their real service member. When instantiated, the spouse is assigned a random happiness; over time, the spouse agent's happiness is affected by the things that keep the service member agent busy and/or away from the family.

Spousal inclination is not changed easily, which can be either a good or bad thing for the service. If the spouse agent is happy, it will take time and many negative events to change that happiness. On the other hand, if the spouse agent is unhappy, it will take time and many positive events to change the spouse's negative feelings about the military.

If the service couple has no children, the spouse will have a slower rate of change in regard to current circumstances; however, once the service couple has children, the spouse's inclination towards the military will change quicker, representing the spouses protection over his/her children. If the service member gets divorced, the agent will either become a single parent (with custody of dependent children), or become single again.

11. Child

Child represents one non-spouse dependent of a service member agent. The initial happiness of a child agent is normally distributed; some will initially love the military, others will initially hate it, and yet most will be apathetic about the military.

As time elapses, the child agents will be affected mostly by the operations tempo of the service. The more the service deploys troops, the more the child agent will dislike the military; if deployment rates remain at a normal/average rate, the child will not get unhappy with the service; if deployment rates go below average, the child will prefer that their parent remains being a service member over their parent becoming a civilian.

As with Spouse agents, happiness or unhappiness of child agents does not change drastically. The happiness is derived by previous happiness and the current situation. However, as long as operations tempo remains high, the happiness of children agents will get worse (thus making the happiness of service member agents worse --- though at a less significant level).

12. Civilian Friend

The role of the civilian friend agents in this simulation is also to affect the service member agent. These agents represent what the service member agent could be doing if it opted to get out of the military to become a civilian. It should be noted that the happiness of civilian friend agents is inversely related to the happiness of the service member agents (if the civilian is happy, then the military agent is made unhappier, if the civilian agent is unhappy with its life, then the military agent is happier with the life it is experiencing).

The happiness of civilian friends is driven by two major parameters. The first is the employment rate in the civilian sector. The employment rate is used to determine whether a given civilian friend is employed or not. If the agents are in technical fields, the odds are that the civilian agent is well employed (whether a given agent is employed or not is governed by the employment rate dictated by the user, and a random number generator). Users should utilize career field employment rates if such rates are available; if not, the user should input the current national employment rate, and understand that their career field may have a different rate.

The second major parameter that affects a civilian friend agent's happiness is the perceived pay gap (an environment factor). If the perceived pay gap is high, then the civilian friend agent's perception is that they are earning much more money in the civilian sector than they would in the military (and are thus they are happy about that). If the perceived pay gap is low or negative, then the civilian friend agents will develop a type of "jealousy" about their military peer's earning more money than they are making.

C. RUNNING THE MPRS MODEL

Users can start the MPRS in one of two ways. The easiest way is by using a Java IDE such as Jbuilder or Forte. However, executing the program from this mode will not allow the user to receive error messages or the output generated by the program. Therefore, the preferred method is to execute the program from the MS-DOS Command Prompt. In order to execute the main MPRS program file, it is necessary to be in the DOS directory immediately above the MPRS directory. At that time, the user can execute the file by typing "java MPRS.MPRS".

Once the program has started, a series of dialog boxes will ask the user for input necessary to run the simulation. The first dialog box simply requests the user's name for future reference. The second request is for the user to decide whether or not to run a demonstration (novice users should utilize this option in order to get a better understanding of how the program works before inputting their own parameters). Should the user choose to observe a demonstration, it will run, and then the program will ask if the user would like another simulation. The user can then choose to observe another demonstration, or move on to creating his/her own simulations.

When the user chooses to create a simulation, the program requests the detailed information necessary to delineate branch of service, career path (officer, warrant officer, or non-commissioned officer), and military occupation specialty (the specific job skill). The user then decides how long the simulation should run (in months). The user is then ready to input personnel management data specific to the chosen servicemembers.

In order to identify specific settings, the user is provided a panel with 15 data fields divided into three categories (an example of the panel is found at figure 4.2 below). The first category contains the number of personnel authorized at each skill level. The second category contains the number of years that service members average at each skill level. The third category contains current group-wide personal information about the service members. This simulation runs best on a computer that contains a 700-megahertz processor (or better). If the simulation appears to run too slow on a slower computer, the user can adjust the simulation by reducing the number of agents (and authorizations) by a constant factor (such as by dividing all numbers by 10).

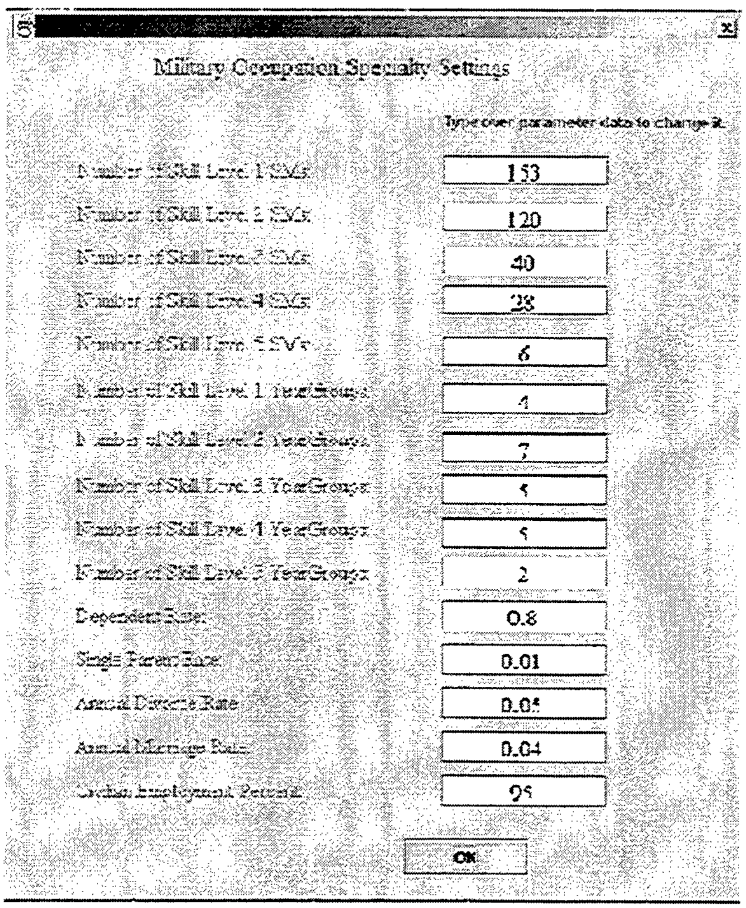

Figure 4.2: Military Occupation Specialty Input Panel

Personal data items currently being taken into consideration include family data (marriage rate, divorce rate, single parent rate, and overall dependent rate), and the unemployment rate of the service member's civilian counterparts. These are the factors that most affect the retention behaviors of service members.

Once the user has updated all of the group-wide personal data fields, the MPRS simulation panel appears (some users may need to adjust the size of the simulator to better fit the available screen). At this time, the user may begin to utilize the MPRS control buttons found at the bottom of the panel. A copy of the panel is found at figure 4.3 below.

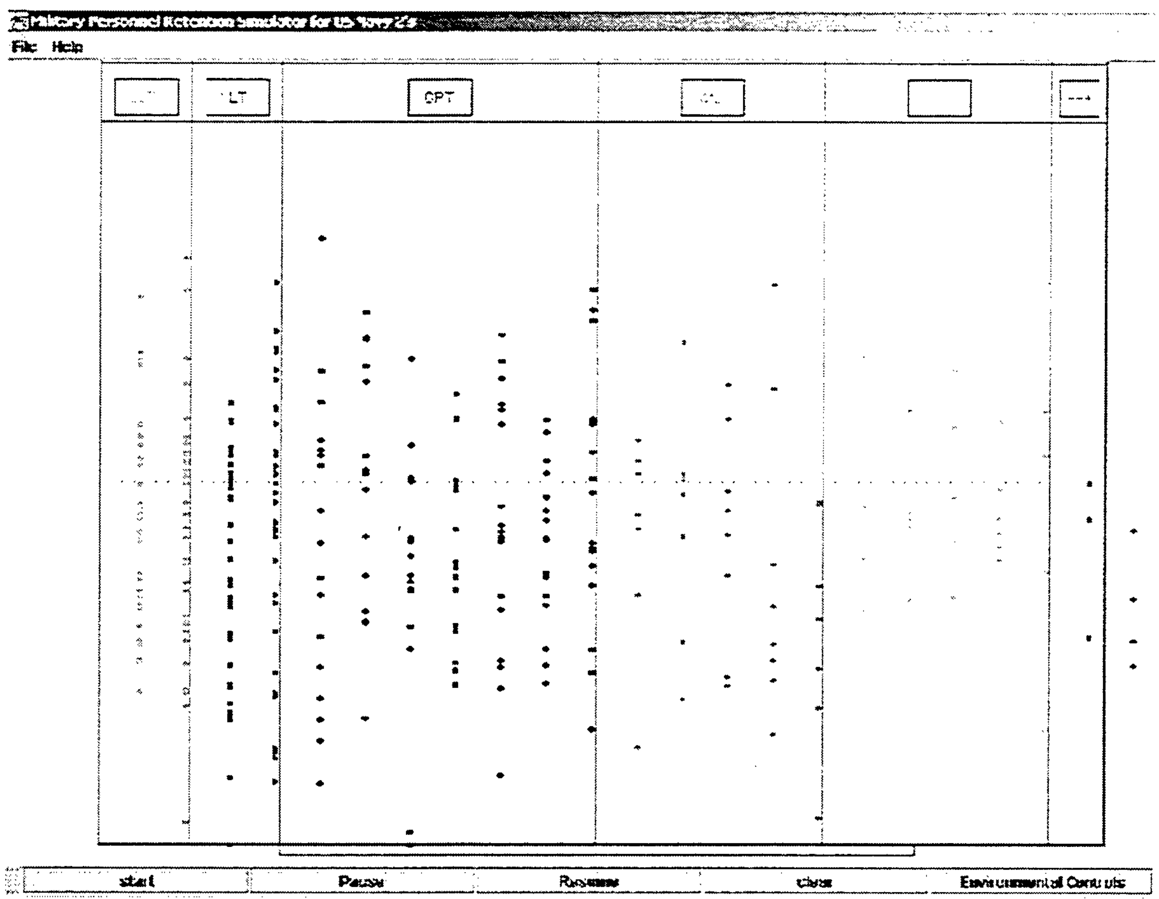

Figure 4.3: MPRS Panel

The MPRS panel is design to emulate the career progression that service members go through during their career. Each service member is depicted by a single dot (an agent) on the MPRS panel. Service member progressions are depicted by their movement from left to right across the screen. Service members change color if they are promoted, and explode off of the screen if they are passed over for promotion, or choose to depart the service on their own.

The panel itself is modeled after the Army officer career progression model used to counsel officers on their career progression (an example of which can be found at figure 4.4). The panel includes six points of interest which are highlighted in figure 4.5:

- Entered onto Active Duty (EAD) Line. This is the first vertical line from the left. The line signifies the point in time when service members enter onto active duty.
- Promotion Lines. These are all remaining full vertical lines. It is at these lines where the service promotes or releases service members from active duty.
- 20+ Years Line. This is the only dashed vertical line. This signifies the point in a service member's career where they will be able to retire.
- Ranks (Column Headers). These are the titles that the service members hold while at the given pay grades.
- ETS line. This is the lower horizontal line. This signifies where service members are eligible to leave the military, and choose to do so.
- Control Buttons. Clicking on these buttons allow the user to run and manipulate the MPRS.

Years of Service	0–5	5–10	10–15	15–22	22–30
Rank	LT	CPT	MAJ	LTC	COL
Schooling	OBC	Captains Career Course	CSC	SSC	
Decisions		★ Functional Area Decision	★ Career Field Decision		
Branch Qualifying		Company Command	Battalion XO/S3 Brigade XO/S3	Battalion Command	Brigade Command
Develop-mental	Rifle Platoon Leader Company XO Specialty Platoon Leader Battalion Staff One Station Unit Training Command Ranger Regiment Long Range Surveillance Platoon Leader	Battalion/Brigade Staff Company Command CTC Observer AC/RC USAREC Service School Instructor ROTC/USMA Faculty and Staff 2d Command Small Group Instructor Ranger Regiment	Brigade/Division Staff Battalion XO/S3 MACOM/DA/Joint Staff CTC Observer AC/RC USAREC Service School Instructor ROTC/USMA Faculty and Staff Brigade XO/S3 Assistant Division G3 (Operations/Training/Plans Exercises) RC Tng Spt Battalion XO/S3 Ranger Regiment Infantry Officer Basic Course Company Command	Brigade XO Battalion Command Division/Corps/MACOM/DA/Joint Staff AC/RC ROTC PMS 2d Battalion Command Ranger Regiment Command Senior CTC Observer/Controller	AC/RC SRAAG/State IG Corps/MACOM Staff Brigade Command DA/DOD/Joint Staff Division/Installation Chief of Staff

Figure 4.4: US Army Infantry Officer Life Cycle

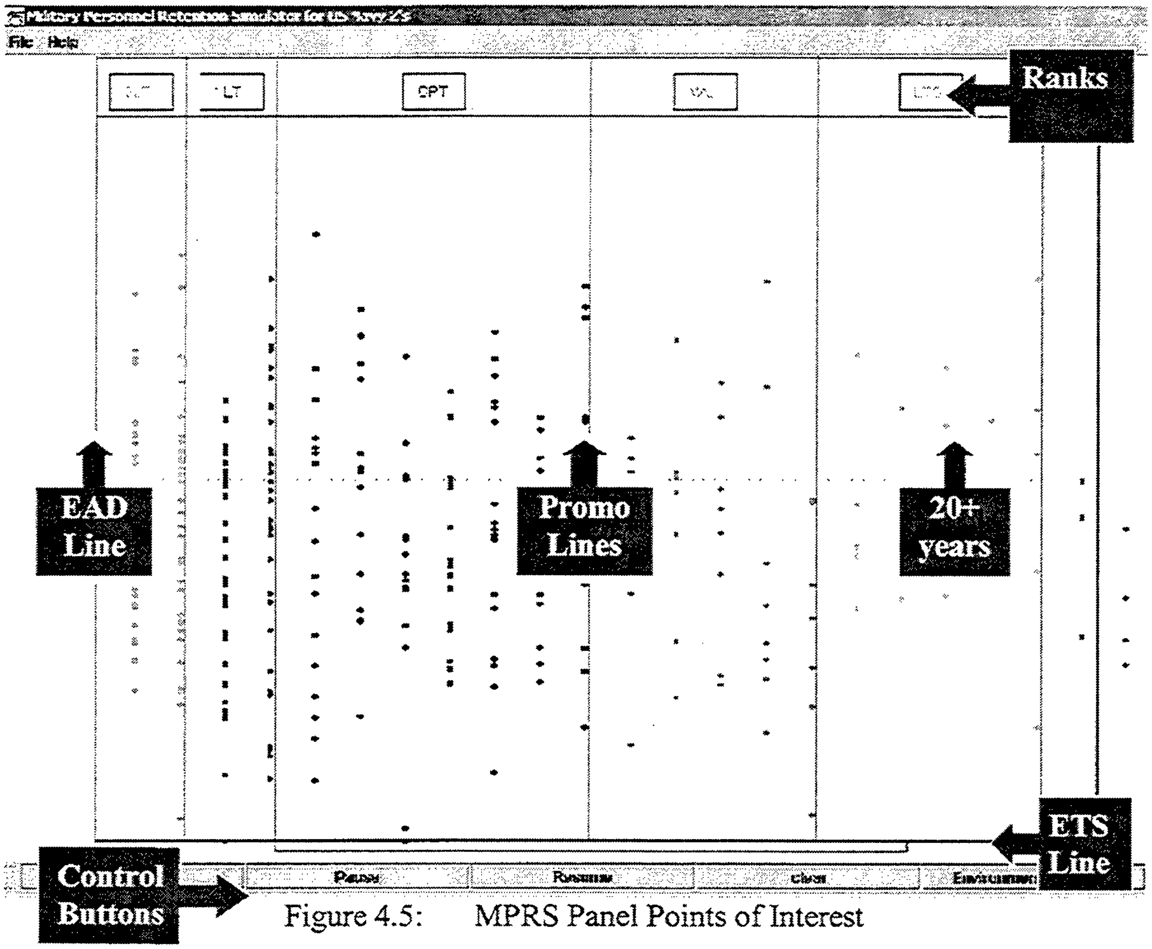

Figure 4.5: MPRS Panel Points of Interest

There are five control buttons at the bottom of the MPRS panel, those being Start, Pause, Resume, Clear, and Environmental Controls:

- Start is used to initiate new simulations. Hitting this button during a simulation run will cause a reset to occur.

- Pause is used to temporarily halt a simulation (particularly useful is you want to reset multiple environmental controls without their making immediate individual changes).

- Resume is used to restart a paused simulation (pushing Start at this point will not effect the desired result).

- Clear is used to clear the current simulation, and eliminate all data that had been collected by that simulation (to include deleting the contents of the ACAP Vector).

- Environment Controls is the last button on the panel. The button is used to manipulate the environmental controls in order to adjust the factors controllable by the DoD (these controls can be adjusted at any time, to include their being adjusted while the simulation is running).

When the Environment Controls button is selected, a dialog box appears which allows the user to manipulate the levels at which the user believes the given service members perceive the Civilian-Military Pay Gap, the Operations Tempo, the Chain of Command Concern, and the DoD-level Concern (the President, down to the particular service agency). An example of the environment controls panel is found at figure 4.6 below.

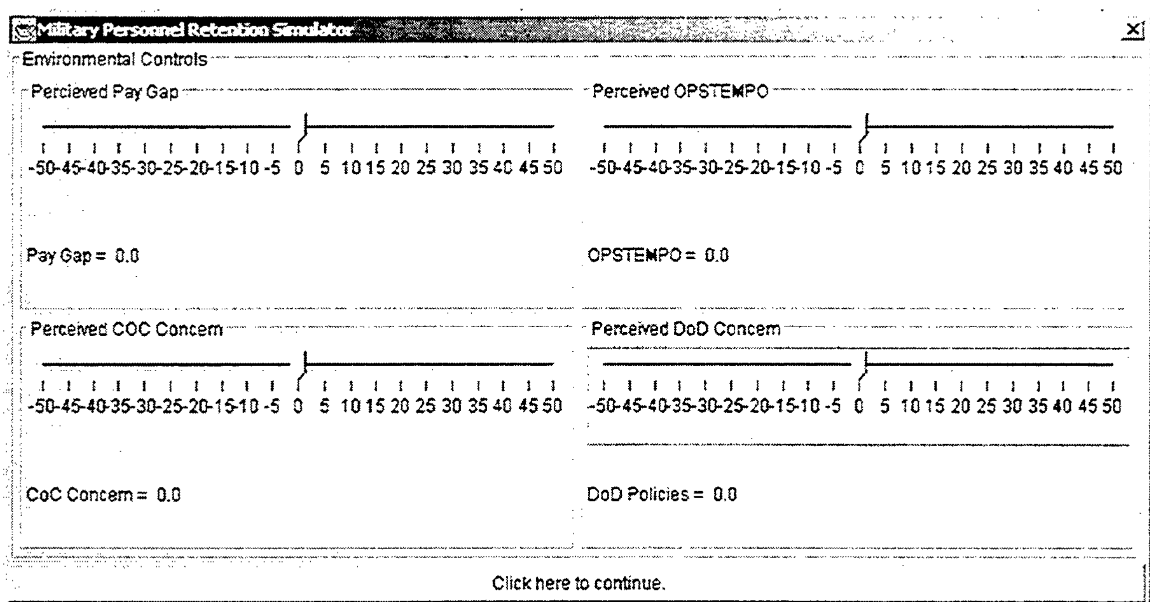

Figure 4.6: Environment Control Panel

D. DATA SOURCES

Data used for the MPRS came from a variety of sources within the Department of Defense. The primary source for data for the MPRS was Professor William K. Krebs of the NPS. Dr. Krebs has been analyzing military retention over the last decade, and was the originator of the idea for using agents to simulate military retention behaviors. His research with Professor Sam Buttrey (also of NPS) and the linear retention theses studies of his students during the 1990s were of great assistance for the creation of this thesis. Professor Krebs is currently working for the Federal Aviation Administration and is on a leave of absence from the NPS.

Other sources for data for this thesis include the Defense Manpower Data Center (DMDC), the Army Office of the Deputy Chief of Staff for Personnel (ODCSPER), and the Army Research Institute (ARI). The DMDC was particularly helpful in providing information about what reasons service members are giving for getting out of the military, and what attitudes young Americans have about the service.

E. OUTPUT ANALYSIS

The MPRS simulation records the military careers of the agent service members throughout each simulation. Each agent is removed from the "active duty" vector when they depart the military (through being passed over for promotion or getting out on their own accord) and placed into another vector for storage (named ACAP for the Army Career and Alumni Program). Once the simulation is complete, all data from the ACAP vector is displayed in the DOS window in report format (see figure 4.7 for an example).

Copying this data into a spreadsheet program (such as MS Excel) allows the user to analyze the differences made when different factor levels are used.

As stated in previous sections, the uniqueness of complex adaptive systems is that the output resulting from minor changes in inputs will result in the full spectrum from rigidity to chaos. The accuracy of the parameter settings will control how accurate the output relates to the real world. Although the scope of this thesis did not include data analysis, I provided the output features in order to provide feedback to users. Full data analysis is therefore assigned as future work for the author and follow-on graduate students.

Agent SSN#	Rank	Grade	TIS	ETS'd?	Released?	Retired?	Eval Rating	Average
100000035	1LT	2	4	True	true	false	COM	4
100000036	1LT	2	4	true	true	false	COM-	3
100000039	1LT	2	4	true	true	false	COM	3
100000040	1LT	2	4	true	true	false	COM-	3
100000042	1LT	2	4	true	true	false	COM-	2
100000043	1LT	2	4	true	true	false	COM	3
100000044	1LT	2	4	true	true	false	COM+	4
100000045	1LT	2	4	true	true	false	BCOM+	2
100000041	CPT	3	6	true	false	false	COM	3
100000048	1LT	2	4	true	true	false	COM	4
100000049	1LT	2	4	true	true	false	COM	4
100000038	CPT	3	8	true	false	false	COM-	3
100000050	1LT	2	4	true	true	false	COM	3
100000051	1LT	2	4	true	true	false	COM-	3
100000053	1LT	2	4	true	true	false	COM-	2
100000054	1LT	2	4	true	true	false	COM	4
100000056	1LT	2	4	true	true	false	COM	3
100000057	1LT	2	4	true	true	false	COM	3
100000059	1LT	2	4	true	true	false	COM-	3
100000061	1LT	2	4	true	true	false	COM-	2
100000046	CPT	3	10	true	false	false	COM-	2
100000052	CPT	3	8	true	false	false	COM	3
100000063	1LT	2	4	True	true	false	COM-	2
100000064	1LT	2	4	true	true	false	BCOM+	2
100000047	CPT	3	10	true	false	false	BCOM+	1

Figure 4.7: MPRS Output

F. SUMMARY

The MPRS is an outstanding tool for helping personnel managers to think about the decisions that service members make, and the factors that effect those decisions. When properly fine-tuned to a specific MOS, the MPRS can help a personnel manager to understand the group-wide effects that service members have upon each other. More importantly, the MPRS helps personnel managers understand that retention behaviors can become non-linear, and that they must therefore be observant for extreme changes over short periods of time.

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V. FUTURE WORK AND CONCLUSIONS

"The toughest thing about being a success is that you've got to keep on being a success." --- *Irving Berlin*

The creation of this thesis and the MPRS model was a great learning experience. When I completed Version 1.0 of the model, I began briefing and demonstrating the MPRS in many forums (to include my Thesis Defense). During several of these events, I was able to obtain professional feedback from colleagues, military personnel managers, NPS faculty members, and simulations community representatives. Conversations with these persons also allowed me to discover the need for other improvements.

During the last three months, I was able to implement several changes to improve the MPRS model; I therefore call this revision of the MPRS model "Version 2.0." However, there were still several other quality recommendations that I was not able to implement prior to the deadline for publishing this thesis. This section describes some of the possible future enhancements that I will strive to make in the future. These changes will result in a second major revision of the model, which will be labeled "Version 3.0." This improved version of the MPRS will be released on/about 1 July 2001, and will be available at www.familyfrench.net. This section also contains the overall conclusion for the thesis.

A. FUTURE WORK

The following list encompasses changes that will provide users with improved MPRS simulations.

1. Add/Implement Additional Relationships and Parameters

There are several relationships and parameters that can be added to the simulation:

- The most important relationship not currently in the MPRS model is that of the leader-follower (employer-employee). These relationships often have a considerable impact upon the happiness of a service member. Right now this relationship is generally covered by the "Perceived Chain of Command Concern," but I feel that it would be more effective if implemented as an agent relationship.
- A significant parameter that should be added is the service member's gender. The retention behavior of females is different than that of males. This will also allow for the model of joint servicemember families.
- Another parameter that can be added is the service member's mission acceptance. In other words, the service member may or may not agree with the policies that he/she is enforcing. If the service member does not believe in the mission, he/she may decide to depart the service; if the service member does agree with the mission, it will reinforce their happiness with being in the service.

2. Improved Functionality

Some MPRS functions can be improved:

- Currently, evaluation reports are given out on a random basis. It is my goal to add functionality that awards evaluations based upon added agent parameters that represent hard work, intelligence, and values. This change would result in the best service member agents getting the best evaluations. In turn, the best agents will be promoted, while the worst will be passed over for promotion.
- Promotion boards do not currently allow for early promotions (below the zone) or for late promotions (after the zone --- the year after a service member's peers were promoted). In scenarios where too many service members get out of the service (from one year group), the year group remains under-manned throughout the remainder of the simulation run. This is contrary to the reality of the services reaching down into later year groups, and early promoting members of junior year groups (which then causes a ripple effect until the deficit is made up).
- The model assumes that the same number of entry-level personnel enter the service each and every year. The model can be improved to manipulate the number of entries, to include setting a maximum limit (which would represent the reality of recruiting). This changing number of accessions would allow the above-mentioned early promotions to occur (as it would be the ultimate cure for the situation).

3. Remove Unnecessary Code/Streamline Code

The MPRS was the very first java program that I have ever written outside of assignments from a Java programming course I sat in on. During the last year, I learned a lot about Java coding. As time went by, my coding became more efficient; however there are still sections of code that are written in very inefficient manners --- this code needs to be streamlined. Another challenge is that the project contains some code that no longer provides significant functionality, but is wrapped around part of code that does provide necessary functionality; removing this code will require time and patience.

4. Add more Random Events (Mutations)

Currently, the only random events that occur are the marriages and divorces of service members. It is my belief that more random events should be added. This includes such events as random deaths, police actions (arrests), and other judicial (e.g. chapter) actions.

5. Improving the Java Panel/Environmental Display

While the MPRS program provides statistical data after a given simulation run, it does not provide the user ongoing information during the actual processing. The model can be changed in order to display data on the sides of the main panel. This change would allow users to analyze events occurring to year groups as they process through the simulation (the ISAAC panel is a good example for this change).

6. Significance Levels of Environment Controls

Currently, each environmental control is weighed evenly. The four control each feed into the happiness of agents in two ways. First, each factor holds a weight of 12.5% of every agent's happiness (for a total value of 50% of every agent's happiness). Second,

the factors are used in varying degrees to determine the other 50% of a specific agent's happiness. The weights of the factors can be changed to comparative values, and thus split up their 50% of the happiness weights in a way that better represents the real world).

In order to make this change, a routine will need to be added that solicits from the users information pertaining to the importance of each factor. A good model for this concept is the Army's Course of Action software (MAPS), which assigns weights based upon stated parameter significance.

B. CONCLUSIONS

This thesis discusses the current problems that the Armed Forces are having with military personnel retention, and how technology can affect it in both positive and negative ways. The MPRS model provided with this thesis is an example of technology assisting personnel managers through the use of multi-agent systems. The MPRS is an outstanding thinking tool for personnel managers, and is meant to supplement, not replace, current linear models. The continued improvements of this and other MAS retention models such as PICAS will help the military better understand the group behaviors of its service members during times of continuous change. This improved knowledge (if acted upon in a timely manner) will enable the military to shift its personnel policies in order to retain the necessary amount of personnel necessary to ensure our readiness goals.

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